

Sugar processing and by-products of the sugar industry

FAO
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BULLETIN

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Food
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by

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FOREWORD

The current low price of sugar on world markets does not provide an economic stimulus for either the expansion or modernization of sugar production. Improving both agricultural and industrial sugar yields as well as adding value to sugar residues and residuals however offers considerable potential for improving the economics of sugar production.

It is hoped that the several opportunities for diversification of the sugar industry described in this bulletin will stimulate an interest in further exploration and exploitation of mechanisms for improving the processing of sugar and its by-products.

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CHAPTER 1

SUGAR PRODUCTION

1.1 Introduction

Sugar cane is a member of the *graminea* family. It is grown in both tropical and subtropical climates. Its main constituents are fibre, sugar and water. Sugar cane originated in New Guinea and was eventually propagated through the small islands of the Pacific Ocean followed by Indochina and India where it was initially processed into syrup and juice. Christopher Columbus brought it to the Americas in 1493. Cuba was the first country in the Caribbean to produce sugar from sugar cane. Today, sugar cane is cultivated on all continents, primarily for sugar production. Globally, between 13 and 15 million hectares are currently under cultivation with sugar cane.

Sugar is produced from sugar cane in tropical climates and from sugar beet in cooler climates. Apart from its use as a nutritive sweetener, sugar has a number of functional properties. These include its contribution to colour development and contribution to the bulk, body and texture of foods. It also has a preservative effect, owing to its ability to lower water activity in food systems (Bernardin, 1978).

Sugar is produced in both liquid and crystalline forms (Table 1). Liquid sugars are primarily used in industrial applications, while crystalline sugar is used in both domestic and industrial applications. This Chapter reviews the production of crystalline and liquid sugars from sugar cane.

Table 1 - Industrial sugars and their characteristics

A. Crystalline sugars

Type	Method of production	Appearance	Uses
Standard Raw sugar	Crystallization of the concentrated juices obtained from sugar cane or sugar beet.	• 0.8 mm sucrose crystals • Covered by a film of molasses and brownish in colour. (pol content 97.5-98.0)	• Raw material for the production of refined sugar and of limited use in the food industry.
Plantation white sugar	Same as for raw standard, the white colour is achieved by the application of SO ₂ in the purification procedure.	• 0.4-0.5 mm sucrose crystals • White colour (pol content 99.4-99.6)	• Domestic consumption and some industrial use.
White sugar produced by carbonation	Same as raw standard, the white colour is achieved by the application of CO ₂ in purification of the juices.	• 0.4-0.5 mm sucrose crystals • White colour. (pol content 99.7-99.8)	• Domestic consumption and various industrial uses.
Refined white sugar	Crystallization of sucrose from a low colour liquor obtained by dissolution, purification and decolourization of dissolved raw sugar	• 0.4-0.5 mm sucrose crystals • White colour. (pol content 99.9)	• Same as the carbonated white sugar.
Amorphous sugar	Crystallization of sucrose from a massecuite obtained from liquor of very low colour at a very high temperature with cooling and agitation.	• 0.55 mm sucrose crystals • White colour. (pol content 99.3)	• Domestic and social consumption; storage for more than two months is not recommended
Powdered sugar	Obtained from sugar dryers subsequent to the production of white or refined sugar or produced by crushing sugar crystals.	• 0.15 mm sucrose crystals • White powder (pol content 99.0)	• Used in bakery products, cereals and confectionery
Glucose Monohydrate	Crystallization of liquor consisting of Invert sucrose.	• Very fine crystals of glucose • White powder	• Pharmaceutical and food Industry for the production of sorbitol, dextrose and ice

Type	Method of production	Appearance	Uses
Crystalline fructose	Cooling of liquor of a high fructose content.	• Very fine crystals of fructose • White colour.	• Nutritional supplement
Cube sugar	Compacting and drying white or refined sugar.	• Compacted sucrose crystals of regular or irregular form. • white	• Domestic and social consumption.

B. Liquid sugars

Liquid sucrose	Decolourization and concentration of refined liquor.	• Sugar solution of 67°Brix; does not contain invert sugars.	• Manufacture of ice creams, soft drinks and condensed milk.
Invert liquid I	Inversion of sucrose liquor by adding acid or by ion exchange.	• Solution of 73-75°Brix containing 40% invert sugar and 36% sucrose.	• Soft drink industry
Invert liquid II	Inversion of sucrose liquor by adding acid or by ion exchange.	• Solution of 77-78°Brix containing 60% invert sugar and 18% sucrose.	• Alcoholic beverages.
Golden syrup		• Solution of 71°Brix containing 55% sucrose and 10% invert sugar.	• Domestic use.
Fructose syrup	Filtration of a glucose and fructose mass.	• Solution at 72°Brix containing 60% fructose.	• Beverage industry and as hypercaloric syrup.

1.2 Production of raw sugar from sugar cane

Raw sugar crystals are the major products of sugar cane processing. Raw sugar crystals are produced at an overall industrial yield of 10.5 to 14 percent relative to the quantity of cane processed, and are generally further refined prior to industrial use and consumption. A flow diagram summarizing the raw sugar production process is shown in Figure 1.

Major steps in the production of raw sugar crystals include:

- Harvest and transport of cane to the sugar factory
- Juice extraction
- Purification of the juice
- Evaporation of water
- Crystallization of sucrose and the production of massecuite
- Centrifugation of massecuite in order to separate sugar from molasses
- Storage of sugar and molasses

Bagasse, a by-product of raw sugar production serves as a solid fuel for generation of the steam requirements of the process. Cogeneration of electric energy from bagasse is also possible, since mechanical energy consumption in sugar processing is relatively small compared to heat energy produced. Surplus energy produced may be delivered to the national grid.

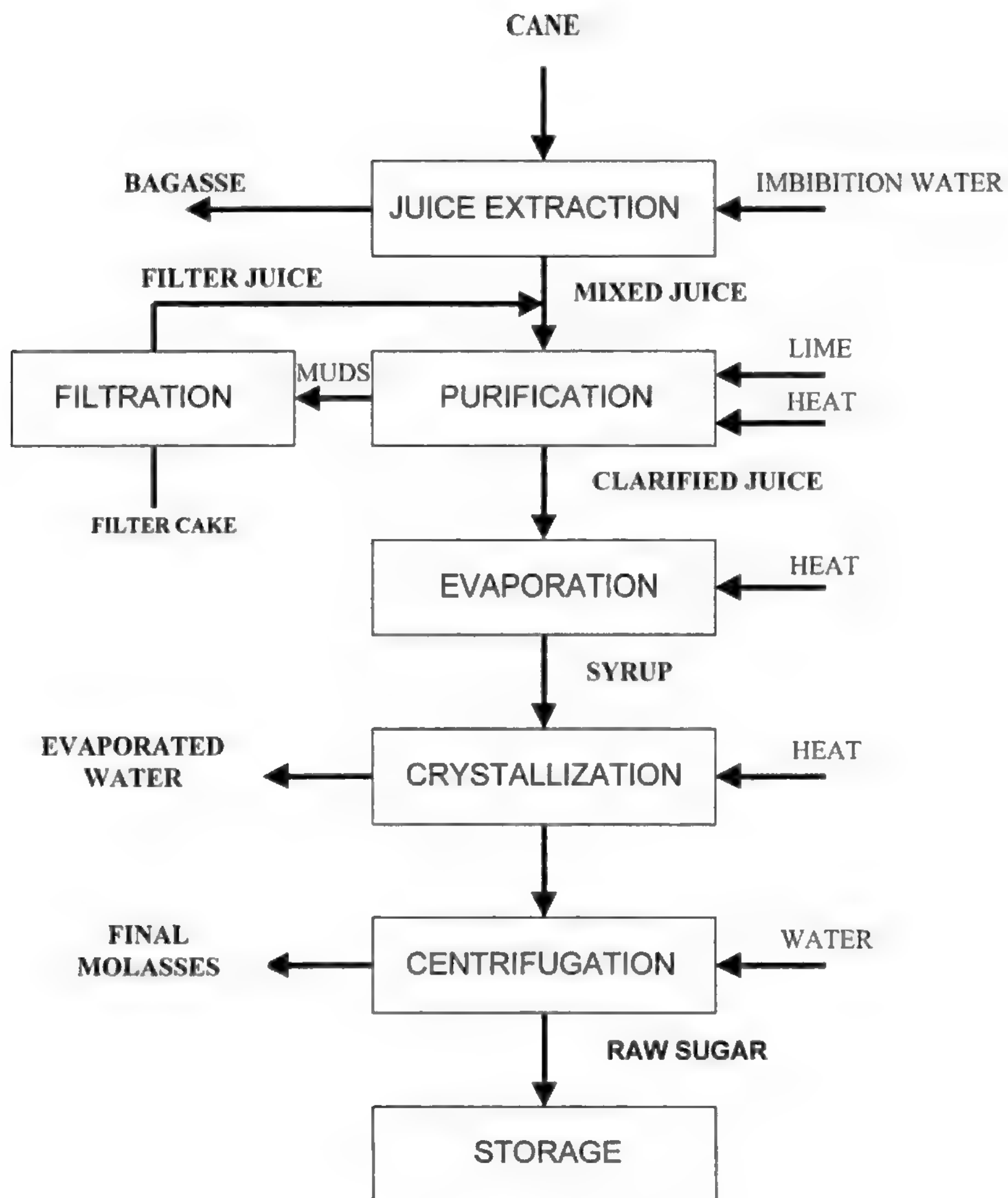


Figure 1 - The production of raw sugar

Harvesting

The overall quality of raw sugar cane is dependent on agronomic practices, and the sugar cane cultivar used in its production. The composition of the sugar cane plant at various stages of maturity is shown in Table 2. Sugar cane for processing into sugar should have both a high sugar content and normal fibre. In addition, it should be free of diseases and processed as quickly as possible subsequent to harvest (Fernandez, *et al.*, 1983).

Table 2 - Composition of sugar cane

Location	Part of the plant	Time (Months)					
		Twelve		Seventeen		Twenty three	
		Weight (kg)	%	Weight (kg)	%	Weight (kg)	%
Underground	Roots and rhizoma	5.07	24	9.79	23	11.59	19
Above ground	Stalk	12.9	56	24.65	58	37.82	62
	Tops	2.35	11	3.81	9	4.27	7
	Leaves	1.98	9	4.25	10	7.32	12
Whole plant		21.4	100	42.5	100	61.0	100

Sugar cane is harvested either by hand or mechanized cutting, the latter being more efficient. Mechanical harvesting equipment is capable of either cutting the intact cane stalk or chopping the cane. Separation of extraneous matter (Table 3) is very critical during harvest, since certain types of extraneous matter, notably cane tops, increase the non-sugar content and interfere with crystallization during processing. Certain designs of harvesting equipment are capable of separating tops and leaves from the cane stalk. The main components of cane tops from different varieties of cane are shown in Table 4 (Celli, 1998).

Table 3 - Proportion and composition of extraneous material¹ in sugar cane

Components	Weight (kg)	Proportion (%)	Extraneous matter (%)
Cane	45	90	--
Tops	3	6	60
Leaves	1	2	20
Grass	0.5	1	10
Soil	0.5	1	10
TOTAL	50	100	100

¹ This sample was taken at the inlet of the milling stage.

Table 4 - Composition of sugar cane tops for various varieties of cane

Component	Proportion (%)				
	Deteil	Bonane	Palat	Bisal	Saillard
Sucrose	3.80	4.01	2.5-8.0	1.8	5.94
Glucose	1.33	6.57	3.0-1.5	4.0	2.33
Water	84.05	-	-	-	-
Fibre	9.96	-	-	-	-
Organic materials	0.38	-	-	-	-
Salts	0.48	-	-	-	-

Source: Valdes, (1949)

Optimal conditions for mechanical harvesting of sugar cane include: the absence of weeds, other plants, rocks and loose metal from the field and a field surface which is either level or gently sloping and thus conducive to operation of the harvester.

Several methods are applicable in separating cane from extraneous matter (EM) such as soil, dry and green leaves and tops. These include:

- Cleaning with the use of a harvester that chops the cane thus separating the tops and the leaves;
- Cleaning at a dry cleaning station subsequent to hand cutting the intact cane stalk;
- Mechanical cutting of the intact cane stalk with exclusion of the tops;
- Cutting of the intact stalk and cleaning with water at a receiving table at the sugar factory in order to separate soil rocks and other materials.

Burning the cane prior to harvest also serves as a method of cleaning. Burning not only reduces the EM content of the cane, but also increases productivity of the cane cutter and lowers harvest costs. In some countries burning is required in order to eliminate animals and reptiles that are a potential menace to the cane cutter.

Although burning eliminates approximately 48 percent of the EM, it is only recommended as a cleaning technology if the cane is processed within twelve hours of harvest since burnt cane deteriorates rapidly and causes reduced crystallization of sucrose, thus decreasing industrial yields. Burning also increases the polysaccharide and oligosaccharide content of the cane. Burnt cane undergoes deterioration more rapidly than green cane, particularly if it is harvested in a chopped form. Green cane harvested with a mechanical chopper has a sustained sugar loss of 1.57 percent within a 24-hour period, while burnt cane harvested under the same conditions has a sustained 4.95 percent sugar loss. Agricultural yields of the second ratoon crop are also lower when the cane is burnt (Amaral and De Armas, 1970; Oliveria, *et al.*, 1996).

Cane is transported to the factory either by truck, railroad wagon, container or cart. Each mode of transportation has specific equipment requirements for feeding the cane into the extraction plant. A crane system may be utilized in order to discharge the cane in an area adjacent to the extraction unit. Alternatively, the cane may be delivered to water-cleaning

tables at feeding angles of 18, 30 and 45°. The cane is sold either on a weight basis or on the basis of its sugar content. In order to maximize sugar yields and quality, the time between cutting and milling of the sugar cane must be minimal.

Juice extraction

The efficiency of the extraction of cane juice is influenced by the method used in preparation of the cane. Cane may be prepared either with the use of rotating knives or shredders. The attainment of an appropriate level of cell breakage during shredding is critical for the extraction process. Heavy shredders are capable of producing a 94 percent cell breakage. Tandem steel rollers powered either by steam turbines or electric motors are used for the extraction of sugar from cane cells. Water (imbibition water) is added to maximize extraction of the juice.

Juice extraction by Tandem Mills

With the use of an extractor having six mills in tandem (Figure 2), a sucrose extraction rate of 96-97 percent and a grinding capacity of 10 000 to 12 000 tonnes per day can be obtained. In recent years however, the use of an installation incorporating two roller mills instead of the classic three rollers has accomplished such positive initial results that its operational and economic advantages are recommended (Valdes, 1977).

The characteristics of the cane, as well as a number of technical and mechanical factors influence the tandem mill operation for juice extraction from the sugar cane:

Characteristics of the cane:

- Fibre content of the cane;
- Quantity of extraneous matter entering the sugar factory;
- Quantity of soluble solids, invert sugars and sucrose in the extracted juice;
- Dextran, starch and polysaccharide content of the extracted juice.

Technical factors:

- Method of cane preparation;
- Juice extracted by the first mill;
- Volume of imbibition water added;
- Volume of juice extracted by each mill;
- Application site of the pith;
- Cleanliness of the tandem area;
- Flow and characteristics of the mixed juice;
- Humidity of the bagasse at the outlet of the last mill.

Mechanical factors:

- Settings of the inlet and outlet of each mill;
- Drainage of the extracted juice from the mills;
- Hydraulic pressures exerted on the top roller;
- Velocity of rotation of each mill;

- Flotation of the top roller;
- Feeding of each mill and grooving of each roller.

Juice extraction by diffusion

Two different types of equipment are used for the extraction of sucrose from the bagasse mat by diffusion technology. One of these, the bagasse diffuser, uses the principle of immersion of the bagasse mat in the juice by counter flow, while the other, a cane diffuser, uses percolation of the juice through the bagasse mat, also by counter flow.

With a bagasse diffuser, a primary mill unit, prior to the diffusion process extracts a portion of the sucrose. The bagasse has a residence time of 45 to 60 minutes within the diffuser, while the juice has a 20 to 30 minute residence time. The process of diffusion with the cane diffuser on the other hand, is somewhat longer, since the process involves the total extraction of sucrose from the cane. The cane has a residence time of 60 to 80 minutes within the diffuser, while the juice has a residence time of 35 to 40 minutes. Schematic diagrams of the processes involved are shown in Figure 2(a), 2(b) and 2(c).

A series of variables govern the results of diffusion processing:

- The degree of preparation of the cane;
- The quantity of juice extracted by the initial extraction unit in the case of bagasse diffusion;
- The pH and temperature of the circulating juices within the diffuser;
- The volume of juice (press waters) that goes out with the bagasse emerging from the diffuser;
- Treatment of the press waters in designs that require a press water treatment;
- The volume of fresh water added;
- The residence time of the bagasse in the diffuser;
- The height of the bagasse mat;
- The percolation rate of the juice.

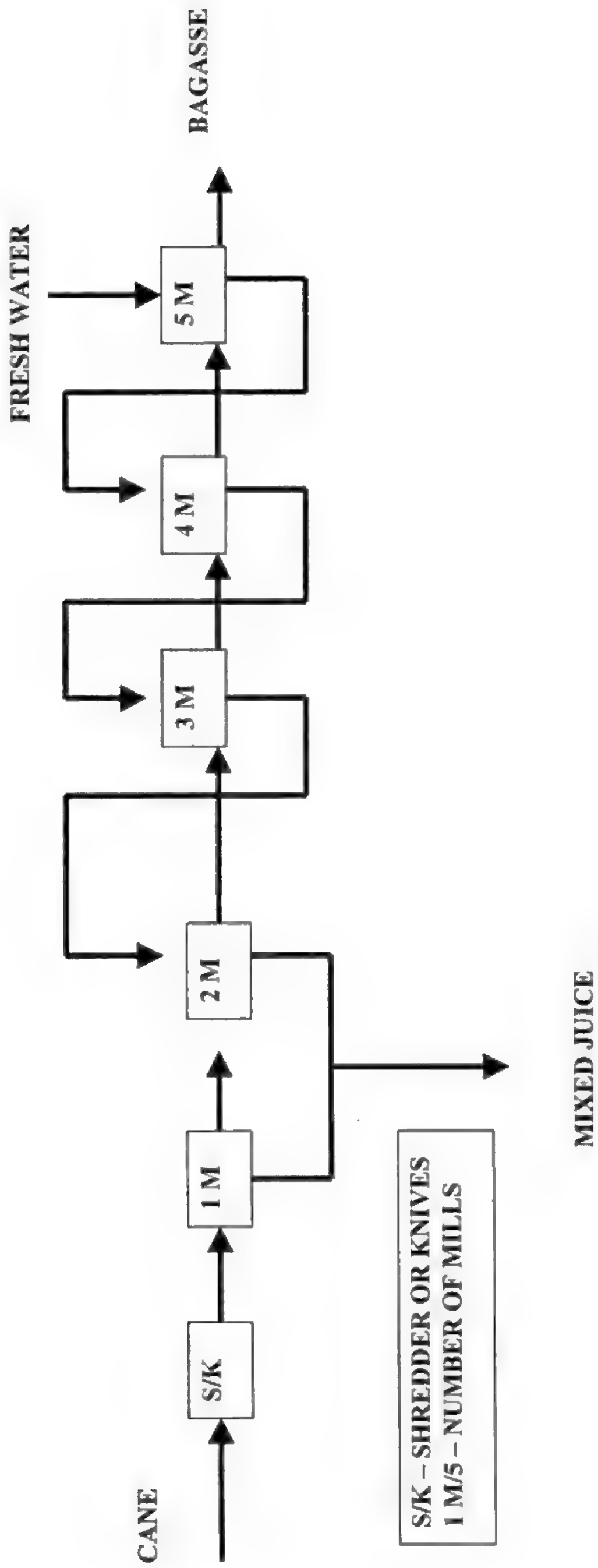


Figure 2(a) – Schematic of juice extraction by tandem mills

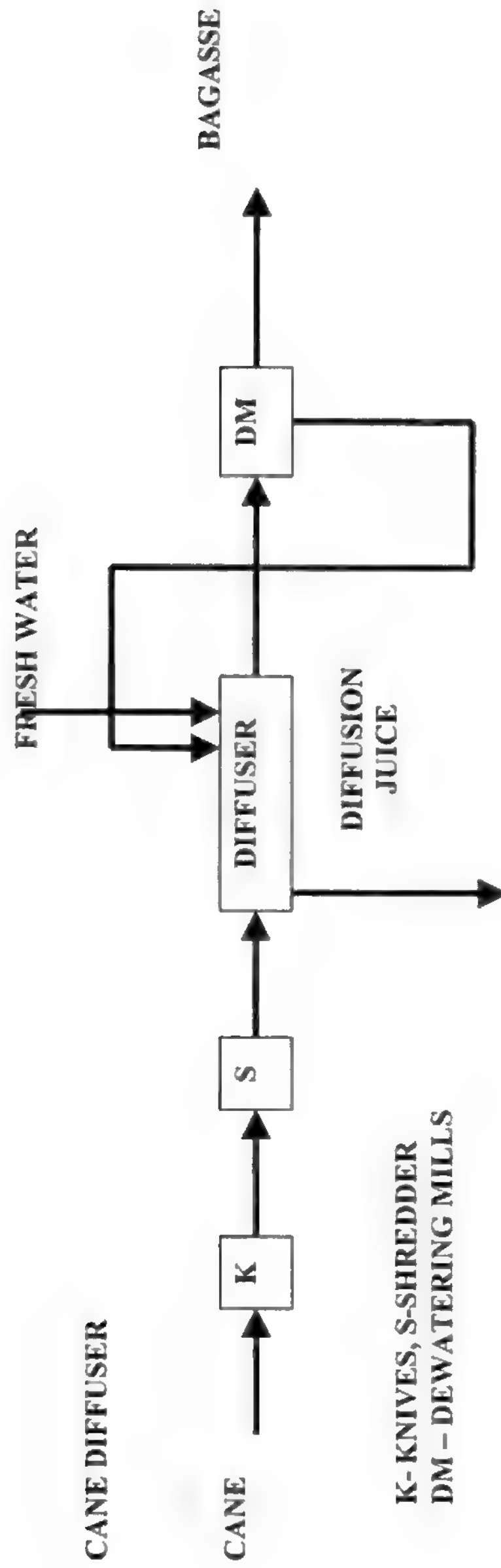


Figure 2(b) – Schematic of juice extraction by a cane diffuser

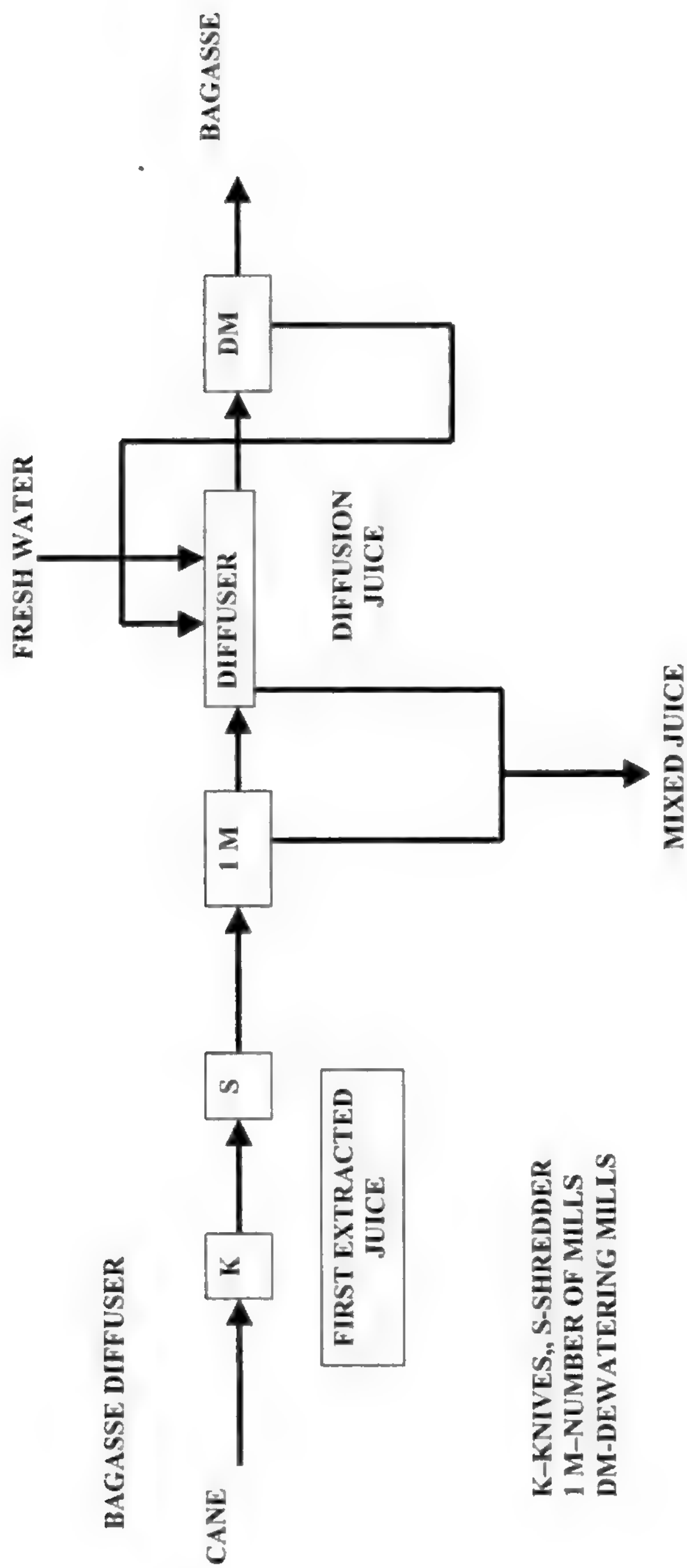


Figure 2(c) – Schematic of juice extraction by bagasse diffuser

Tandem mill extraction vs. diffusion extraction

The main advantage of a diffusion system over a tandem mill with an equivalent sugar extraction rate, is the lower power requirement of diffusion systems. Diffusion systems in addition, generally require a lower level of maintenance. The steam consumption of diffusion systems is however 3 to 5 percent higher than that of the tandem mill system, owing to the requirements for evaporation of larger quantities of water.

Losses and efficiency at the extraction stage of the manufacturing process, are determined on the basis of the sugar losses in the bagasse, the quantity of sucrose (pol) left in the bagasse and by the quantity of pol in the bagasse compared to pol present in the sugar (Table 5).

Table 5 - Efficiency indicators for the extraction stage of raw sugar production

Efficiency index	Low	Medium	High	Very high
Reduced pol extraction to 12.5% of fibre on cane	93 or lower	93.1-94.5	94.6-96.5	More than 96.5
Pol in bagasse	1.8 or lower	1.8-2.5	2.6-3.5	More than 3.5
Pol in bagasse referenced to pol in cane	3.5 or lower	3.6-5.0	5.1-6.0	More than 6.0

Purification

The purpose of purification is to produce a clear juice with a low quantity of non-sugars and dense mud. This is accomplished by a series of steps, which include liming, heating, settlement of impurities, separation of the clear juice from the mud by filtration and treatment of the filtered juice.

The first step of the purification process involves the addition of lime in order to separate impurities from the juice in the form of a calcium phosphate precipitate (mud), while heating is conducted in order to precipitate any albumin present. In cold liming, lime is added to the juice at room temperature until the clear juice attains a pH of 6.5 to 7.1. In hot liming on the other hand, the juice is heated to 103 to 105°C and lime is added until the clear juice reaches a pH of 7.8 to 8.0. In fractional liming, lime is added to the juice at room temperature, until a pH of 6.5 to 6.8 is attained. The juice is heated to between 103 and 105°C and lime is again added until a pH of 6.5 to 7.1 is attained (Valdes, 1977; Valdes, 1989; McAdam and Tait, 1996).

Mud resulting from the liming process is sedimented in a clarifier, while the clarified juice is recovered. The purity of the clarified juice thus obtained is 1.0 to 1.5 points greater than that of mixed juice. At a temperature of 95°C, the clarified juice has a soluble solid content of 14 to 16°Brix. It contains 0.1 to 1.2 percent of invert sugars, and has a pH of 7.0 and a maximum pith content of 0.5 mg/l, which consists of small particles of bagasse (Hale

and Whayman, 1970; Bango, 1998; Perez, 1998).

Mud produced by settlement in the clarifier is mixed with small particles of bagasse or pith to form a material that can be filtered through a vacuum filter. Vacuum filtration of the mud results in juice of poor clarity, which is recycled for further purification. The filter cake or cachaza obtained subsequent to vacuum filtration represents 3.0 to 4.0 percent of cane, and contains sugar, which was not extracted during filtration. This sugar is counted as a loss of the sugar production process.

Evaporation

The process of evaporation is designed to concentrate the juice. Various designs of evaporators are used in the sugar industry. The Roberts design is the most popularly used. The best efficiency of evaporation is attained when steam is used at temperatures, which prevent sucrose inversion or decomposition. The level and rate of sucrose inversion during evaporation is influenced by the temperature, velocity and retention time of the juice in the evaporator.

One of the most important factors, which affect the evaporation stage, is scale formation. Scale formation influences the period over which the evaporator can operate without requirements for cleaning the heating surface. Various degrees of scale formation, classified as light, moderate, heavy and excessive can occur (Table 6).

Table 6 - Classification of levels of scale formation in evaporator tubes

Classification	A (gr scale/m ² heat surface)	B (gr scale/tonne cane)
Light	Up to 200	Up to 10
Moderate	200-800	10-50
Heavy	800-1 500	50-100
Excessive	More than 1 500	More than 100

Source: Argudin, (1968)

With light scale, the evaporator can be operated over a nine to 12 day period. With moderate scale it can be operated over a six to nine day period, while with heavy scale, it can be operated over a four to six day period.

Application of magnetic flow to the cane juice can decrease the occurrence and degree of scaling within the heat transmission tubes. Use of this technology has been shown to increase the operational time by more than 30 percent, while reducing requirements for chemical products that are used for cleaning these surfaces.

The use of magnetic devices is advantageous in that:

- Larger quantities of cane can be processed without requirements for stopping in order to clean the heat surface;
- There are reduced requirements for chemical products for cleaning the heating surface;

- Fewer sugar losses from cane left in the field or waiting to be processed at the sugar factory;
- Reduced detrimental environmental impact due to lower residuals;
- Reduced bagasse consumption during cleaning stoppage and higher soluble solid content in the syrup;
- Less corrosion of the evaporator plate due to reduced acid consumption.

The product of the evaporation stage is sugar syrup of 78 to 86 percent purity, a soluble solid content of 60 to 65°Brix and containing 3.5 to 4.5 percent of invert sugars. The sucrose concentration of this syrup is adequate to allow its crystallization at the next stage of the process.

Crystallization and Centrifugation

The objective of crystallization is to produce sucrose crystals. The rate at which crystallization takes place is dependent on the degree of supersaturation of the molasses or syrup, the purity of the molasses or syrup, temperature, and the relative motion of the crystal grains and molasses.

The first step of the crystallization process involves increasing supersaturation of the syrup to between 1.25 and 1.40, by boiling in vacuum pans in order to effect the spontaneous production of sugar crystals. These sugar crystals then grow to the size of massecuite crystals. A massecuite boiling system consisting of two (if the syrups are less than 80 percent pure) or three massecuite is subsequently used to exhaust the sucrose from the molasses by converting it to crystalline sugar (Bostock, 1992).

The massecuite thus produced is sent to the cooling crystallizers in order to allow further sugar recovery. At this stage, the temperature of the mass is decreased, its supersaturation level is increased and remaining sucrose is transferred from the mother liquor to the crystal. Sucrose recovery during cooling crystallization is influenced by the temperature, viscosity and density of the massecuite, as well as the crystal yield.

In a three massecuite system (A, B, C), the A-massecuite and B-massecuite are directed to commercial sugar production, while C-massecuite is used as seed for the production of A- and B- massecuite. Molasses referred to as “final molasses” is separated from the crystalline sugar by centrifugation. A traditional three massecuite boiling system is shown in Figure 3.

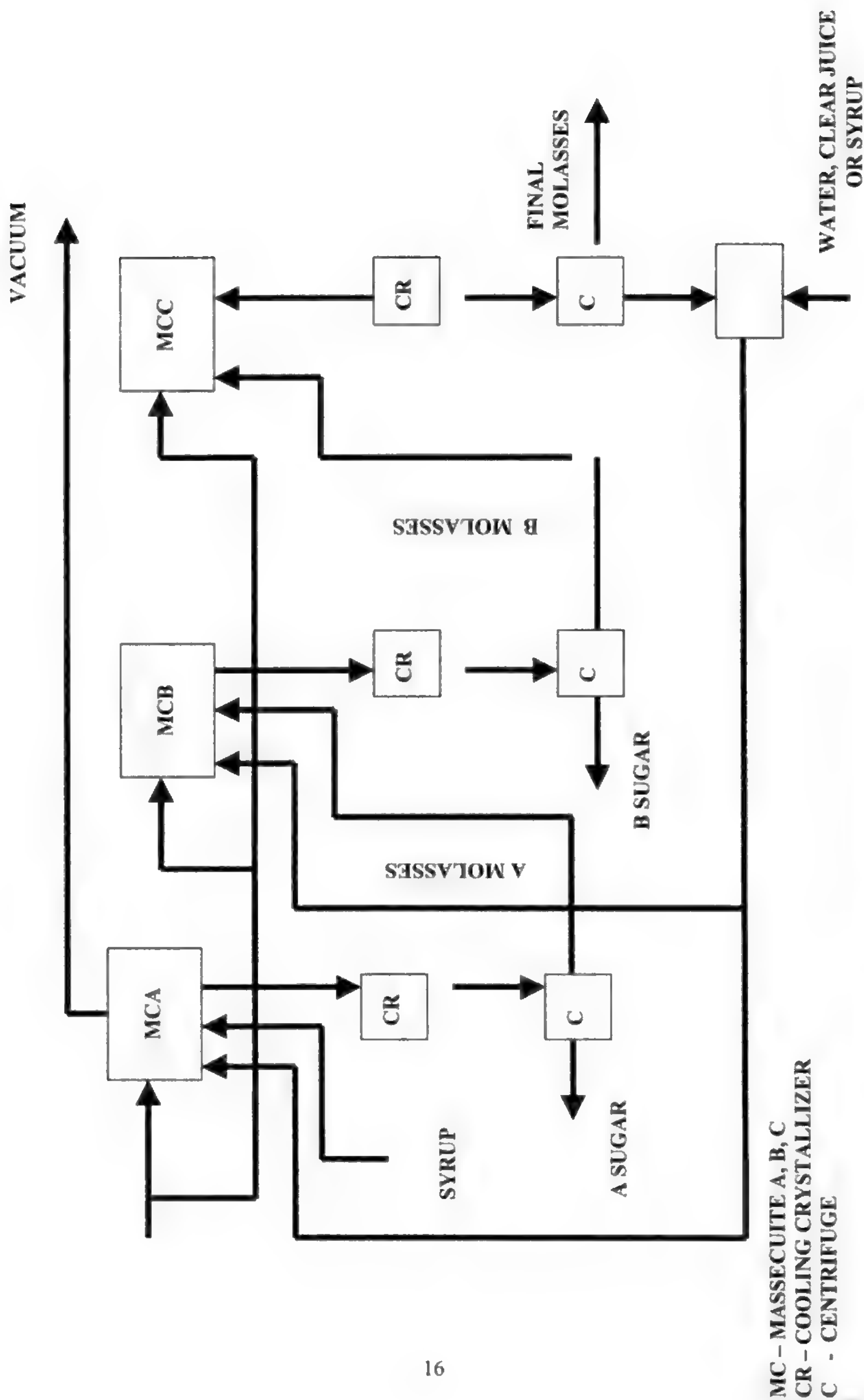


Figure 3 -- The three massecuite system used in raw sugar production

Losses at the crystallization stage of raw sugar production occur due to poor recovery of sucrose from the final molasses. Poor post-harvest treatment of the cane, as well as industrial factors contribute to this poor recovery.

With respect to post-harvest treatment, a long time lapse between cutting and grinding of the cane results in an increase in both polysaccharide, and oligosaccharide content, thus increasing the viscosity of the molasses and decreasing diffusion of sucrose from the mother liquor to the crystal. Resultant sugar crystals are consequently somewhat deformed, being elongated.

Industrial factors, which contribute to poor recovery, include:

- Breakage of crystals, particularly elongated crystals, during centrifugation, resulting in the production of small crystals in the molasses, thus increasing its sugar content;
- Destruction of invert sugars during liming, clarification and in the first evaporator vessel, thus increasing the solubility of the sucrose and decreasing sugar recovery;
- The introduction of ash into intermediate materials, through the introduction of soil with the cane, the use of raw water for imbibition in the extraction units and use of lime of low purity.

Composition of the final molasses:

Brix	88.0
Apparent purity	32-38
Inverted sugars	16-28
Ashes	10-12
Quantity/cane	17-28 l/tonne cane

Storage

Raw sugar is generally stored either in bags or in bulk. During bulk storage, raw sugar undergoes quality deterioration in the form of increased colour and diminished polarisation. Increased colour is the result of sucrose degradation caused by the chemical reaction between amino acids and degraded invert sugars, known as the Maillard reaction.

Increasing the pH and decreasing the temperature to 35°C can however prevent colour deterioration. A reduction in pH is accomplished through the addition of either sodium hydroxide or lime to the syrup. Temperature can be satisfactorily decreased with the use of proper cooling equipment.

The ability of invert sugar to absorb water increases the humidity of sugar during storage. This increase in humidity can result in hardening. Recommended parameters for the bulk storage of sugar are:

Polarization	more than 97.5
Humidity	lower than 0.5 percent for raw standard; lower than 0.3 percent for high pol
Initial colour	lower than 30°Horne
Initial pH	higher than 6.5
Storage temperature	30°C raw standard.; 35°C high pol
Relative humidity of air inside the warehouse	less than 70 percent
Storage time	seven month for raw standard.

Consumption of auxiliary materials, fuel and energy

The production of raw sugar requires the use of a variety of chemical reagents as well as fuel and energy (Table 7).

Table 7 - Chemical and energy requirements for the production of raw sugar

Chemical Products	Index
Calcium oxide (gr/tonne cane)	550-650
Phosphoric acid (eventual)	To reach 300-350 ppm in mixed juice
Flocculant (ppm) (eventual)	4-8 ppm in relation to the velocity of sedimentation of the juices
Surface active agent (ppm) (eventual)	50-100 ppm in MCA, MCB and 100-300 ppm in MCC
Sodium hydroxide 98% purity (gr/tonne cane)	80-110 *
Hydrochloric acid (at 32%)	80-110 *
Utilities	
Steam (kg/tonne cane)	40-55 **
Electric energy (kW-hr/tonne cane)	20-30 ***

MCA, MCB, MCC—Massecuite A, B, C.

* The quantity required depends on the requirements of each factory.

** Depends on the thermal scheme installed.

***Depends on the type of equipment used (electric motors, steam machines, steam turbines).

Production efficiency and sugar quality

Two main indices are used in assessing the efficiency of raw sugar production:

1. An *industrial yield* which is used internationally in reference to a sugar of 96 polarization. This yield is used in order to facilitate comparison with other factories or within the same factory over different time periods.

Industrial yield is determined on the basis of the quantity of sugar produced at 96 pol, relative to the quantity of cane processed. This yield ranges between 9 and 14 percent, based on the sugar content of the cane and the production efficiency.

2. *Factory efficiency* is determined on the basis of the quantity of sugar recovered from sugar entering the factory in the form of cane.

Sugar recovery refers to the quantity of sugar that is lost during various stages of processing, e.g. extraction, purification and crystallization. These losses can be referenced to the quantity of mixed juice, the quantity or pol of sugar in the mixed juice and the quantity of sugar in the cane. The quantity of sugar in the cane is generally used as the reference point. Table 8 shows an example of the sugar losses at different stages of the sugar manufacturing process.

Table 8 - Sugar factory losses and recovery

Process Stages	Normal Range of losses
	% pol
Bagasse	4.0-6.0
Filter mud	0.5-0.7
Undetermined losses	0.7-0.9
Molasses	8.0-11.0
Total	13.0-18.0
Sugar recovery	82.0-87.0

Losses at the extraction stage for a diffusion unit or tandem mill are expressed as the quantity of sugar loss in the bagasse. Losses at the purification stage are related to sugar loss in the filter mud or cachaza. Losses at the crystallization stage are expressed on the basis of the quantity of sugar lost in the final molasses. Undetermined losses are related to the quantity of sugar that is lost by inversion of the sucrose at the mills, during clarification and evaporation, and through spilling of the juice, syrup or massecuite. In certain cases where poor sedimentation takes place at the clarification step, it is necessary to lower the level of sedimentation by releasing juice to the factory drainage system.

Efficiency is defined as the quantity of sugar that is recovered from the sugar entering the factory in the form of cane.

A Total Quality System has been introduced for assessing raw sugar. This system allows analysis not only of end products, but also for all the intermediate processes that compliment production quality standards. Quality standards for sugar have been established by the ISO (International Organisation for Standardisation).

1.3 Production of plantation white sugar

Plantation white sugar is produced by direct processing of sugar cane. It is of a higher sucrose content, is less coloured than raw sugar, and can be used directly for both domestic and industrial consumption. Plantation sugar is processed using either carbonation or sulphitation technologies.

The manufacture of plantation white sugar, differs from that of raw sugar at the purification, evaporation and crystallization steps.

Purification

Juice extracted from the cane must be intensely purified in order to separate non-sugar constituents such as colloids and insoluble particles. Coloured material must also be separated in order to obtain a quality white sugar. Carbonation and sulphitation technologies enhance purification of the juice.

Carbonation technology

The first step of carbonation involves heating the mixed juice to a temperature of 55°C, and adding lime until a pH of 10.5 to 11.0 is attained. CO₂ is then applied, and the juice is filtered using pressure filters. Filtration results in separation of calcium carbonate mud. The juice is again heated to a temperature of 55°C, following which lime is added and CO₂ is applied until a pH of 8.4 to 8.6 is attained. Pressure filtration is again performed.

A temperature of 55°C is recommended for the attainment of good filtration, optimum separation of non-sugars and minimum destruction of invert sugars. Subsequent to evaporation, SO₂ is added to lower the pH of the syrup to 7.0 (Yero, 1985).

With the exception of India, this process is not widely used in sugar cane-producing countries, owing to requirements for large quantities of lime and CO₂. A limestone kiln is normally used for the production of both the CO₂ and lime, demanding a higher investment and operational cost in comparison to the sulphitation process. A schematic diagram of the carbonation process is shown in Figure 4 (Fernandez, 1990).

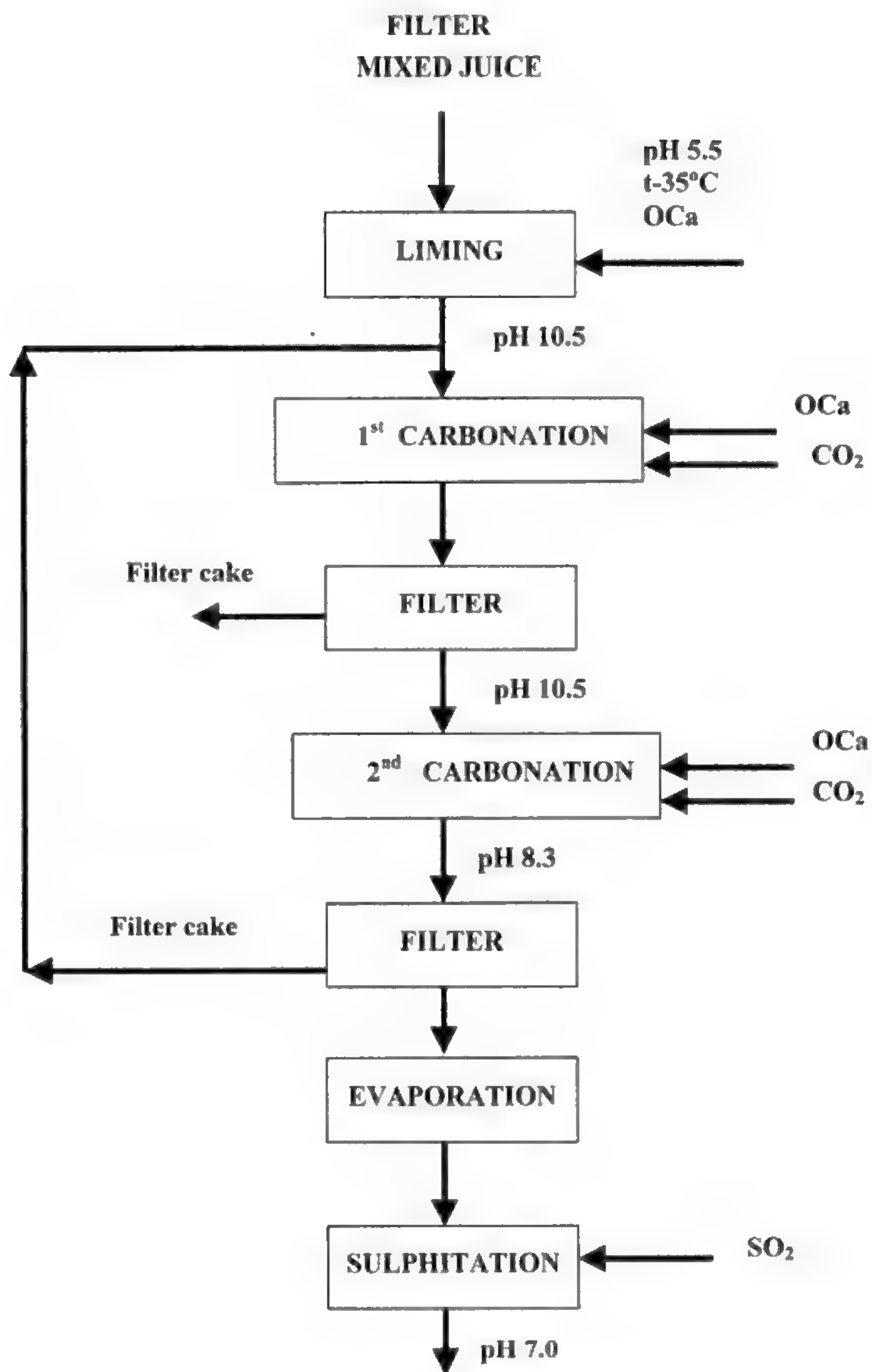


Figure 4 - Production of plantation white sugar by carbonation technology

Sulphitation technology

A number of approaches have been used in the purification of juice by sulphitation technology. Cold or hot acid sulphitation and double liming are the most commonly employed. A flowchart of the sulphitation process is shown in Figure 5.

Cold acid sulphitation involves the addition of SO_2 to the juice in order to attain a pH of 3.8 to 4.2 at ambient temperature. A pH differential of 1.0 to 1.2 between the pH of the mixed juice and pH of the juice after its sulphitation is recommended. Lime is then added to increase the pH to between 7.2 and 7.4. Finally the juice is heated to between 103 and 105°C prior to sedimentation of impurities in a clarifier.

Clarified juice should leave the clarifier at pH 6.6 to 6.8 in order to prevent excessive scaling in the evaporator tubes. The mud obtained on sedimentation is filtered using vacuum filtration, following which the resultant juice filtrate is recycled and is again allowed to undergo sulphitation.

Hot acid sulphitation involves heating the juice to 70°C, prior to lowering the pH to between 3.8 and 4.2, through the application of SO_2 . Lime is then added to the juice until a pH of 7.2 to 7.4 is attained. The juice is heated and clarified by processes similar to those used in cold acid sulphitation.

The double liming process consists of first heating the juice to 70°C, following which lime is added until a pH of 7.2 to 7.4 is attained. Sulphur dioxide is then added until a pH of 5.4 to 5.6 is attained. Lime is again added to increase the pH to 7.2 to 7.4, following which the juice is heated to between 103 and 105°C.

Limitations of Sulphitation Technologies

During the production of white sugar by sulphitation of the juices, calcium sulphite is formed and calcium sulphate scales, which precipitate, on surfaces are produced. These scales are very difficult to remove from the heating surfaces, and must often be removed by mechanical, chemical or combined mechanical and chemical cleaning procedures.

Chemical cleaning can be performed by treatment with a solution of sodium hydroxide, followed by a solution of hydrochloric acid. Substitution of a 20 percent solution of sodium hydroxide by sodium carbonate, results in improved cleaning of sulphites and sulphates. Sodium fluoride is also particularly effective in removing hard scale. Mechanical cleaning is sometimes required subsequent to chemical cleaning.

Sulphitation technology can also cause corrosion at various stages of the process. This corrosion can however be avoided through a number of precautionary measures:

- The use of pipes made of stainless steel or polyester with glass;
- Coating the tanks with epoxy resins;
- Use of evaporator plates made of low carbon steel;
- Application of an anti-corrosion agent with the acid used for cleaning the heating tubes in the evaporator;
- Use of aluminium in the channels for the flow of the condenser water from the condensers to the spray pool;
- Installation of the sulphur oven outside the factory, at such a location that

the wind direction is away from the factory.

Evaporation

The evaporation process for the production of plantation sugar is identical to that used in raw sugar production. SO₂ is applied to the syrup in order to decrease the pH from 6.5 to 5.5 and to minimize colour formation during the vacuum process.

Clarification of the syrup can also be used in order to minimize losses and enhance sugar quality. Basic steps of the clarification process include the addition of phosphoric acid, surface-active agents and phosphate, followed by heating and aeration of the syrup and the addition of flocculant. The syrup is then treated in a special clarifier (Diaz, 1984).

Clarification results in:

- A 50 percent decrease in the colour of the original syrup;
- A 55 percent decrease in the viscosity of the original syrup and a 30 percent decrease in boiling requirements of the massecuites in the vacuum pans;
- A 50 percent decrease in the insoluble constituents of the original syrup;
- A 50 percent decrease in the polysaccharide, starch and gum content of the original syrup;
- An increase of 1.2 units in the purity of the syrup;
- An increase in sugar recovery as well as a lower colour in the commercial sugar.

Crystallization and Centrifugation

At this stage of the process, sucrose present in the syrup is crystallized and molasses is separated from the sugar crystals by centrifugation (Figure 6).

Various crystallization schemes are used in the production of plantation white sugar:

- One version of the three massecuite processes involves the direct crystallization of the A and B-massecuites for producing the A and B-sugars. The C-sugar produced is dissolved and returned to the syrup. In this scheme, the C-massecuite undergoes double centrifugation to increase its purity and decrease the colour of the C-sugar.
- Another version of the three massecuite approach involves a double seeding process, whereby only the A-sugar is packed. During this process, the C-sugar is used as the seed for the B-sugar and remaining C-sugar is dissolved. All of the B-sugar is dissolved and recycled to the clarified juice or syrup.

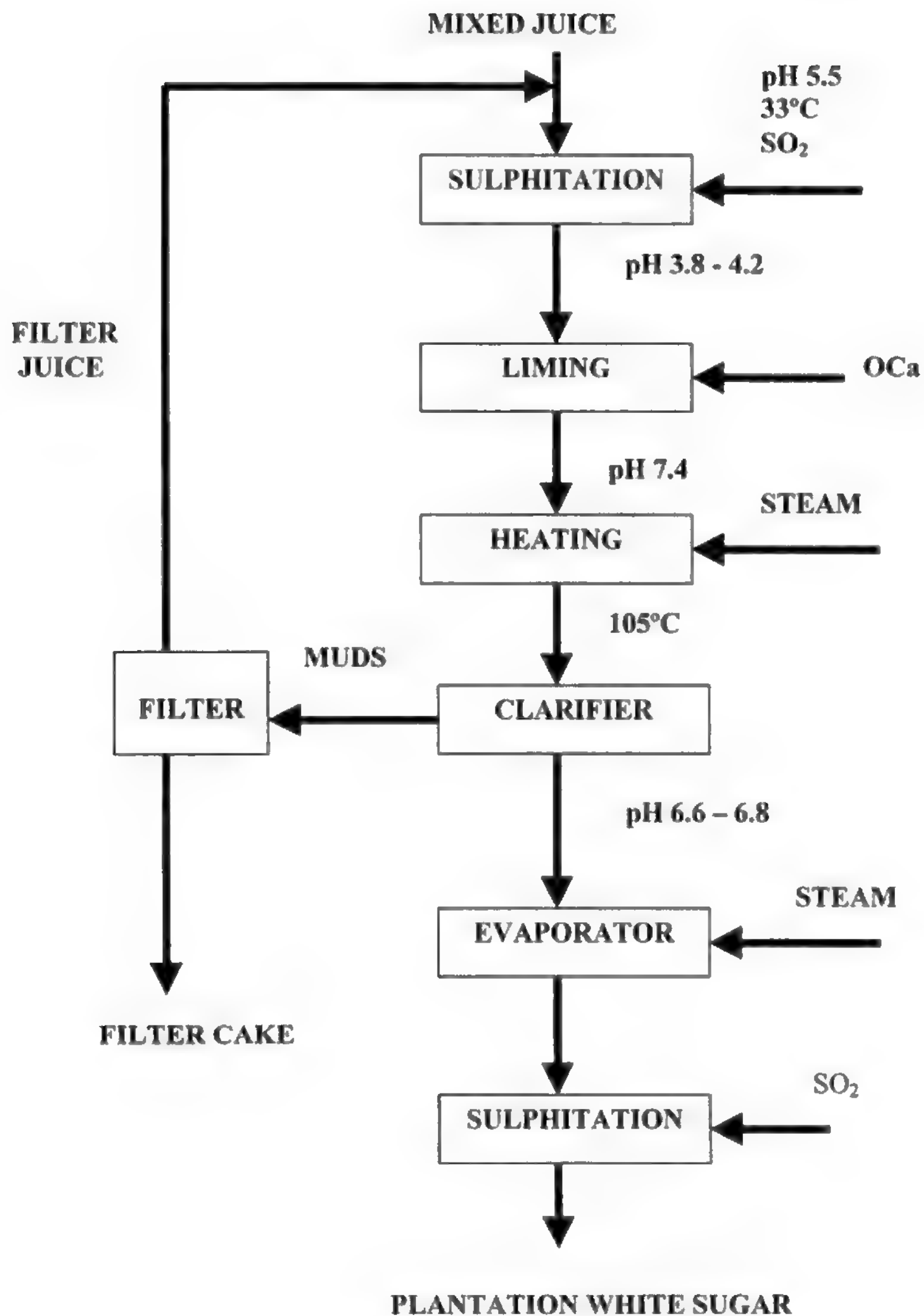


Figure 5 - Schematic of the production of plantation white sugar by sulphitation of the mixed juice using the cold acid process (Source: University of Natal, South Africa, 1996)

Both the temperature and humidity of the sugar must be decreased in order to preserve the quality of the sugar during storage. Drying with the use of either a rotary or fluidised bed dryer decreases the moisture content of sugar recovered by centrifugation.

Table 9 compares the chemical composition some samples of plantation white sugars produced by sulphitation with CODEX standards for white sugar (Leon, 1972).

Table 9 - Comparison of physical and chemical properties of plantation white sugar produced by sulphitation in Cuba, Brazil and Mexico with the CODEX Standards for white sugar

Parameters	Cuba	Brazil	Mexico	CODEX White A	CODEX White B
Polarization	99.4-99.7	99.7	99.5	99.70	99.50
Colour ICUMSA	200-300	230 and 420 *	150-250	60	150
Humidity (%)	0.07	0.05	0.06	0.10	0.10
Ashes (%)	0.15	0.10	0.10	0.04	0.10
Insoluble (%)	0.03	6-10 **	0.06		
Inverted sugar	0.10		0.10	0.04	0.10
Magnetic particles (mg/kg)		3-22			
Dark spots/100g		30			
Grain size (mm)	0.40-0.60	0.55			
SO ₂ content (ppm)	70	13 ***	20	20	70

* Two types of sugars are produced. The special with low colour (230 ICUMSA) for domestic consumption and the standard quality (420 ICUMSA) for sugar refining.

** Scale from 1 to 10

*** Mean value from 1994-1995 crops Copersucar Annual Report

Storage

Sugar undergoes colour change during storage under conditions of high ambient temperature. This colour change is more pronounced in sugars produced by carbonation. There is also a positive correlation between the ash content of the sugar, and colour increase during storage. Sugars of high ash content show a relatively larger increase in colour. Similarly, sugar bags stored at the upper part of the pile undergo deterioration more rapidly, than do those at the bottom.

In order to preserve quality, sugar is stored in Brazil under precisely controlled conditions:

- The temperature of the sugar must not exceed 35 to 40°C, since temperatures in excess of this range result in the loss of SO₂ during cooling thus resulting in an increase in the colour of the sugar;
- Sugar is produced with a lower colour (166 ICUMSA) than the standard (230 ICUMSA), in order to balance the colour increase during its storage.

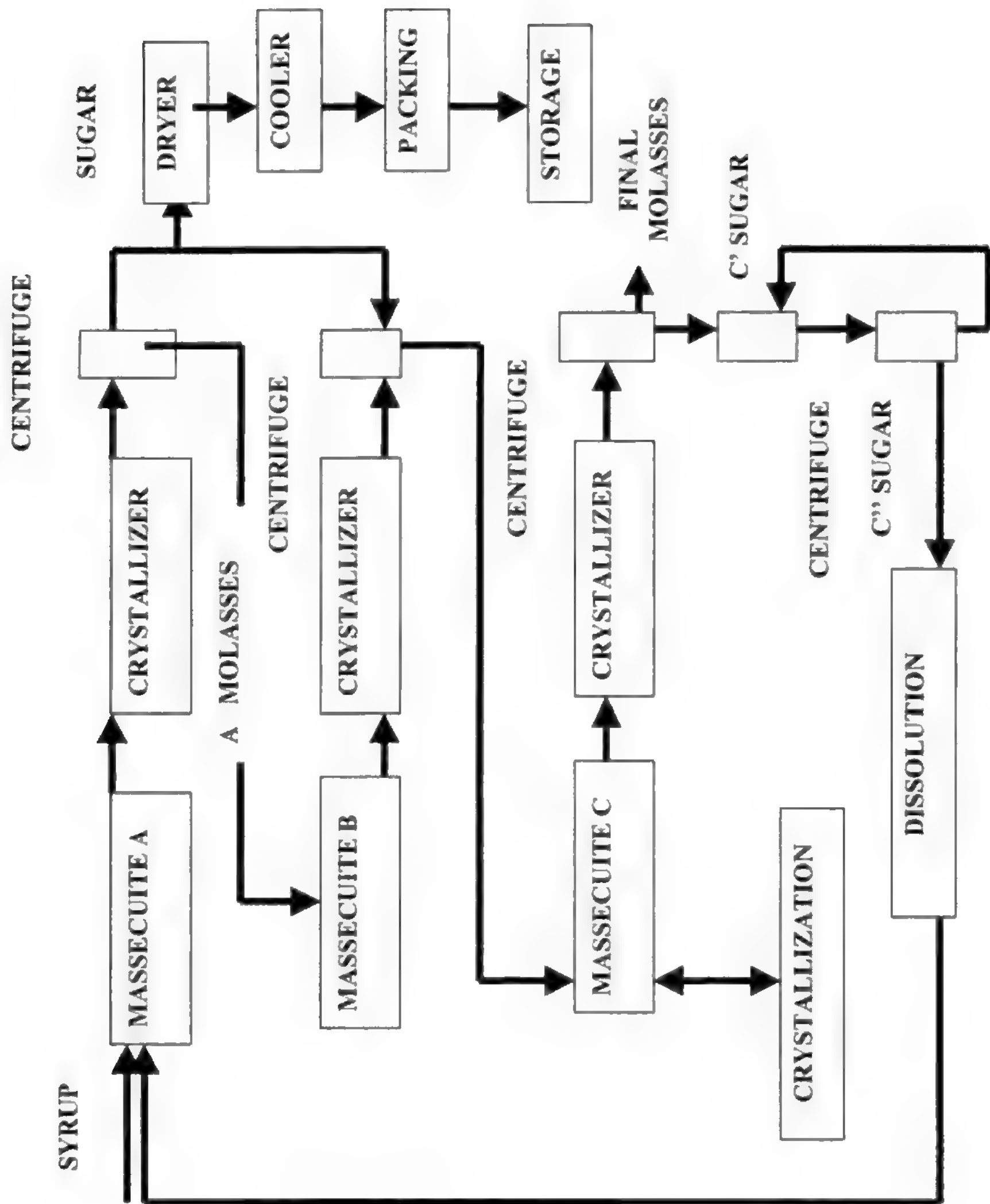


Figure 6 – Crystallization, centrifugation and drying steps in the production of plantation white sugar

Consumption of auxiliary materials, fuel and energy

The production of plantation sugar requires the use of a variety of chemical reagents as well as fuel and energy. Consumption of these products and utilities are summarized in Table 10.

Table 10 - Consumption of chemical products and utilities for the production of sugar by sulphitation technology

Chemical products	Index
Calcium oxide (gr/tonne cane)	1 600-2 300
Phosphoric acid (eventual)	To reach 300-350 ppm in mixed juice
Sulphur A. Juice * (gr/tonne cane) B. Syrup	300-700
	100-200
Flocculant (ppm) (eventual)	4-8 ppm in relation to the velocity of sedimentation of the juices
Surface active agent (ppm) (eventual)	50-100 ppm in MCA, MCB and 100-300 ppm in MCC
Sodium hydroxide 98% Purity (gr/tonne cane)	100-550 **
Hydrochloric acid (at 32%)	120-270 **
Utilities	
Steam (kg/tonne cane)	45-60 ***
Electric energy (kW-hour/tonne cane)	20-30 ****

MCA, MCB, MCC—Massecuite A, B, C.

- * The quantity to apply depends on the system used for the purification of the juice in each factory.
- ** Depends on the intensity of the scale. Sometimes it is necessary to execute mechanical cleaning. Also some industries only use mechanical cleaning.
- *** There is an increase of 6-10 percent in comparison to a raw sugar production.
- **** Depends on the type of equipment used (electric motors, steam machines, steam turbines). Additional equipment (compared to that required for raw sugar production) such as a sugar dryer, a C-centrifuge for a double purging of the C-massecuite, etc. is required indicating an increase of 6-8 percent.

Production efficiency and sugar quality

The production of plantation white sugar normally results in greater losses in the filter cake and final molasses, than occur during raw sugar production. Table 11 compares the production of raw sugar with the production of plantation white sugar by sulphitation and carbonation technologies.

During the carbonation process both the juice and filter cake are of relatively higher purity. Sugar quality is better than that produced by sulphitation, however production cost is 10 percent higher than with the use of sulphitation technology (Cordoves, *et al.*, 197; Ministry of Agriculture, Havana, Cuba, 1998).

Table 11 - Comparison of production parameters for raw sugar and plantation white sugar

Parameters	Clarification	Sulphitation	Carbonation
Overall sugar recovery *	84.00	80.00	81.60
Industrial yield **	11.50	10.95	11.17
Steam consumption % cane	52.00	55.70	60.60
Filter losses *	1.50	2.50	2.50
Limestone consumption % cane	0.50-0.65	0.09-0.40	2.50-4.00
Sulphur consumption % cane	--	0.04-0.07	0.025-0-030
Molasses purity	35.00	35.00	37.00
Molasses losses *	8.50	11.5	9.90
Quality of sugar	--	White	Refined
Cost of production (%)	100	105	115

* Pol (% Pol in cane)

** Weight of cane /weight sugar

1.4 Production of refined white sugar

Refined white sugar is an industrial sugar, which contains the highest quantity of sucrose. It has a low invert sugar and ash content and low colour. It is used for both domestic and industrial consumption. At the industrial level, it is used as a fermentable ingredient for the production of beer, desserts, soft drinks and canned foods.

Technology for the production of refined white sugar

Refined white sugar is produced from raw sugar via a number of steps:

- Affination of raw sugar;
- Dissolution of the affinated sugar;
- Purification of the liquor;
- Decolourization of the liquor;
- Concentration of the liquor;
- Crystallization, massecuite production and centrifugation;
- Cooling and drying of sugar for storage.

Affination of raw sugar

The objective of the affination step is to separate low purity molasses present in raw sugar, from the high purity sucrose crystals. This involves blending the sugar with the affining solution, followed by washing with hot water of high purity in centrifuges. The level of affination required is dependent on the quality of the raw sugar (Yero, 1985). Raw sugar produced by the double seeding process, for example, does not require a centrifugation step.

Dissolution of affinated sugar

The affinated sugar is dissolved in a hot liquor (sweet water) of high quality, to produce a solution having a soluble solids content of 55 to 68°Brix.

Purification of the liquor

In addition to sugar, the affinated liquor thus obtained contains non-sugar constituents, which include pith or small particles of bagasse, soil, starch, dextran and polysaccharides which must be separated. In some cases strainers are used to separate insoluble materials from the affinated liquor.

The affinated liquor may be purified using either the phosflotation process or by carbonation technology.

The phosflotation process involves the addition of lime and phosphoric acid to the affination liquor, followed by aeration and heating to a temperature range of 80 to 85°C. Calcium phosphate produced in the process, removes the non-organic sugars by flotation in specially designed clarifiers. The scum is removed from the surface of the clarifier by rotating arms, while the clarified liquor is filtered using pressure filters made of diatomaceous earth. A flow chart of the production of refined white sugar by sulphitation technology is shown in Figure 7.

This process which incorporates the use of relatively low-cost materials achieves a 20 to 40 percent decrease in the colour of the liquor. The process is simple to operate, has low maintenance requirements, can be automated and requires low manual labour. Colour removal can be enhanced with the addition of quaternary ammonium salts, which further increase separation of the non-sugars by increasing the size of the flocculent particles (Bugarenko, *et al.*, 1981).

The addition of a special cationic surface-active agent TALOFLOC, in conjunction with phosphoric acid and lime as an acid neutraliser, has been shown to reduce the retention time at the clarifiers from one hour to a few minutes. A smaller filtration surface is required, and a 70 percent rate of decolourization is achieved with the use of this combination of reagents.

Carbonation technology is operationally more complex than the phosflotation process. Apart from its higher maintenance requirements, larger quantities of scum or mud must be separated by filtration. Carbonation technology however results in greater colour removal (30 to 50 percent), and thus the production of sugar of better quality than that produced by phosflotation. The process involves the addition of lime and carbon dioxide in two or three steps at different temperatures and pH values in order to precipitate calcium carbonate, which binds extraneous matter such as colour, ashes, pith and other insoluble substances such as soil. The calcium carbonate precipitate is separated by pressure filtration using cotton or

synthetic cloth filters. A flow chart of the production of refined white sugar by sulphitation technology is shown in Figure 8 (Delgrado, *et al.*, 1990).

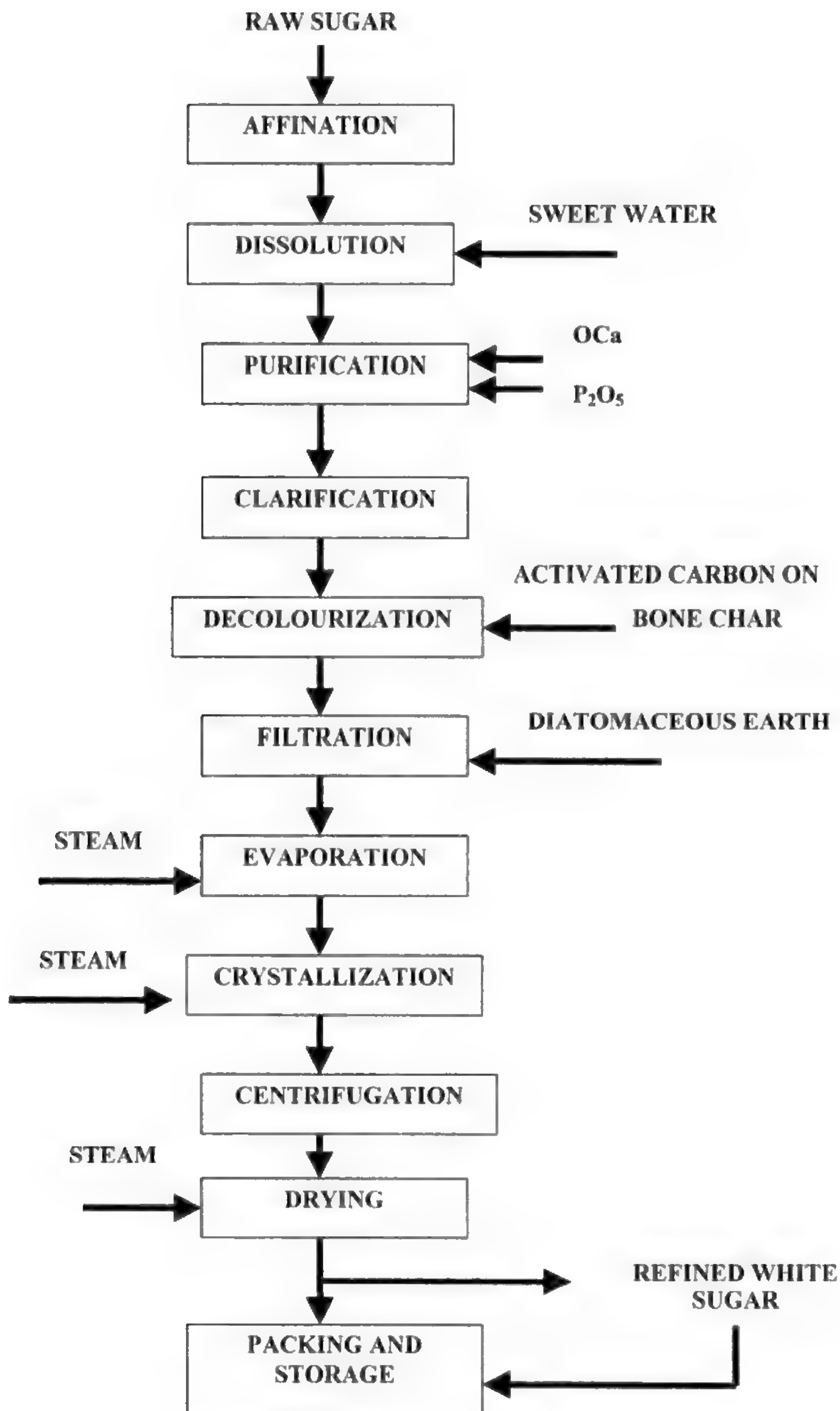


Figure 7 - Flowchart for the production of white refined sugar by phosflotation and the use of activated carbon or bone char

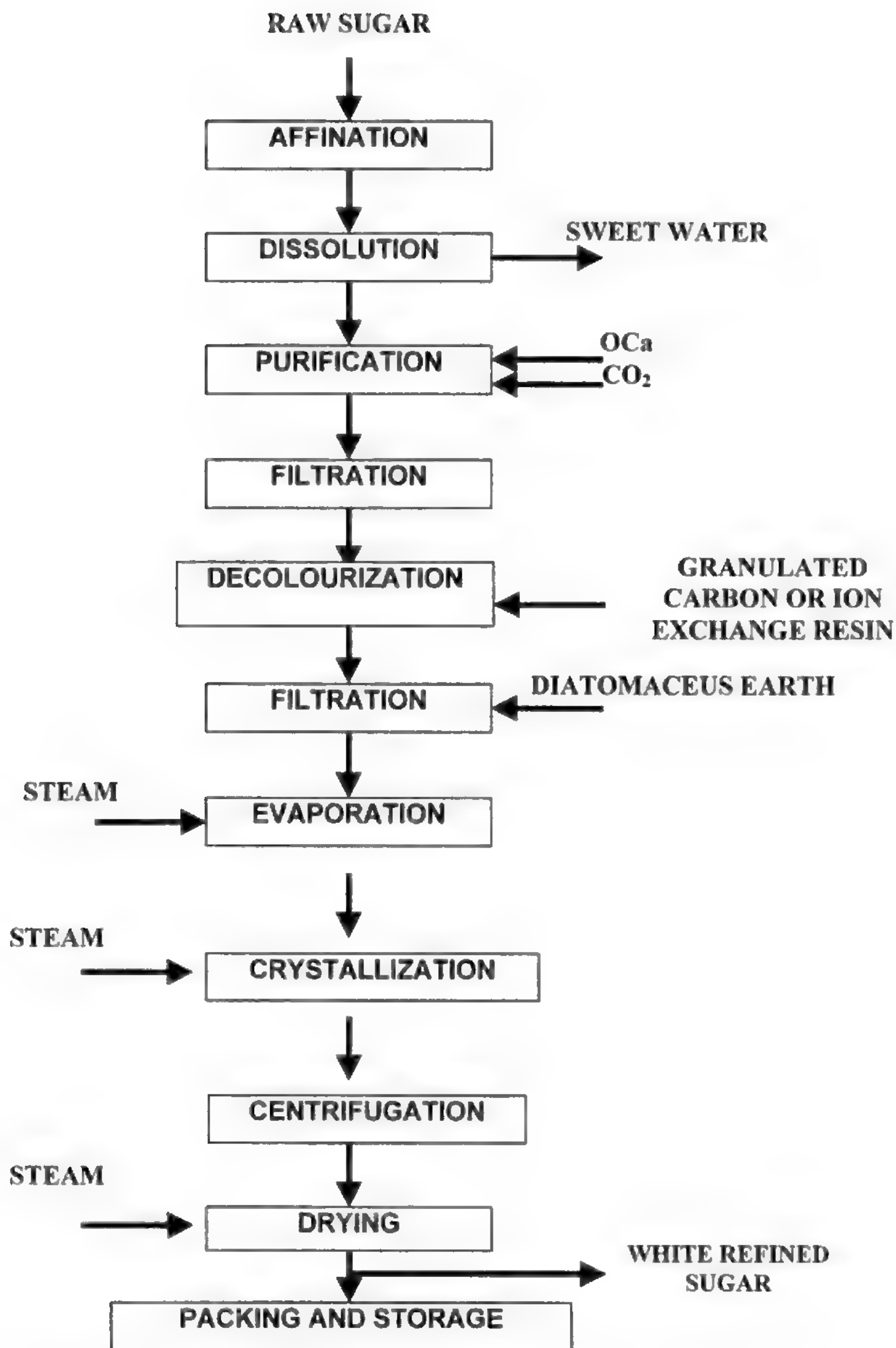


Figure 8 - Flowchart for the production of white refined sugar by carbonation and ion exchange resin or granulated carbon (Delgado, *et al.*, 1990)

The starch content must be controlled at the purification step, since the presence of starch adversely affects filtration of the liquor. A starch content as low as 50 ppm can negatively affect filtration of the liquor. Addition of alpha amylase is recommended for starch levels exceeding 150 to 200 ppm Murray, *et al.*, 1974).

Decolourization of the liquor

Decolourization is the most important operation in the production of white refined sugar since colour and ash present in the liquor must be removed. Colour originates from caramelization of the sugar; melanoidine formation or plant pigments, which are naturally present. Caramelization occurs upon exposure of a juice, syrup, liquor or massecuite to high temperatures. Lime interacts with invert sugars and also contributes to colour. Melanoidines, which are highly coloured substances, are produced by the reaction between amino acids and invert sugars.

Ion exchange resins, bone char and activated carbon are widely used in decolourization of the liquor, although the use of ozone and cooling crystallization technologies have been investigated for this purpose.

Activated carbons and bone char

Carbon products are capable of separating both ash and colorants. Granulated activated carbon is more effective in lower quantities than is powdered carbon. In the case of bone char, the lower the bulk density and particle size of the material, the greater is its decolourising ability (Silberstein, 1971).

Bone char contains 10 percent carbon and can be used and regenerated in many cycles. Granulated carbon on the other hand contains 60 percent carbon, which can be used over a 28 to 30 day period, and regenerated. Granular carbon is incapable of removing ash, while up to 60 percent of ash is removed by bone char. Table 12 compares the efficacy of different types of carbon as decolourizing agents (Ocampo, 1984).

Ion exchange resins

Ion exchange resins can be used in a number of different applications during sugar processing:

- | | |
|--|---|
| 1. Decolourization of liquors | Strong basic anionic resin in chloride cycle. |
| 2. Deionisation of liquors | Weak cationic and anionic resin in H ⁺ and OH ⁻ cycle |
| 3. Demineralization and inversion of liquors | Strong acid cationic in H ⁺ cycle. |
| 4. pH increase of invert liquors | Weak basic anionic resin in OH ⁻ cycle. |

Decolourization of the sugar liquor is accomplished with the use of strong basic anionic resins (Ortiz and Garcia, 1988; Celle and Herve, 1979).

Table 12 - Effect of various carbon types on decolourizing sugar liquors

Carbon type	Decolourization (%)	Ash removal (%)	Invert sugar removal (%)	Operation cycles
Activated powder	80	0	Increases with increase in carbon concentration	Needs 5 kg/tonne of refined sugar
Bone char	85	40	20	3 hours of retention time
Granular carbon	85	0	-	2 hours of retention time
Granular carbon + bone char	95	40	-	2 hours of retention time in each column
Granular carbon + ion exchange resin	85	80	-	2 hours of retention time

Source: Alonso (1985)

Concentration of the liquor

The decolourized liquor undergoes evaporation in order to increase its soluble solid content. This is generally done using a multiple effect evaporator.

Crystallization, massecuite production and centrifugation

The liquor and syrup of each massecuite is subjected to crystallization. This can be performed using a four massecuite scheme because of its simplicity, ease of control, and ability to produce a uniform final product. The processes involved are summarized in Figure 9.

The A, B, C and D sugars derived from the process, must be mixed in specific proportions in order to obtain the required quality of refined white sugar. Crystal size of the final product varies in accordance with consumer preference (R.C. Chambon Prospectus).

Cooling and drying of sugar for storage

Temperature and humidity must be controlled in order to preserve sugar quality and to prevent the sugar from caking or melting during storage. Storage temperatures of less than 40°C and relative humidities ranging between 0.03 and 0.05 percent are optimal for maintaining sugar quality during storage.

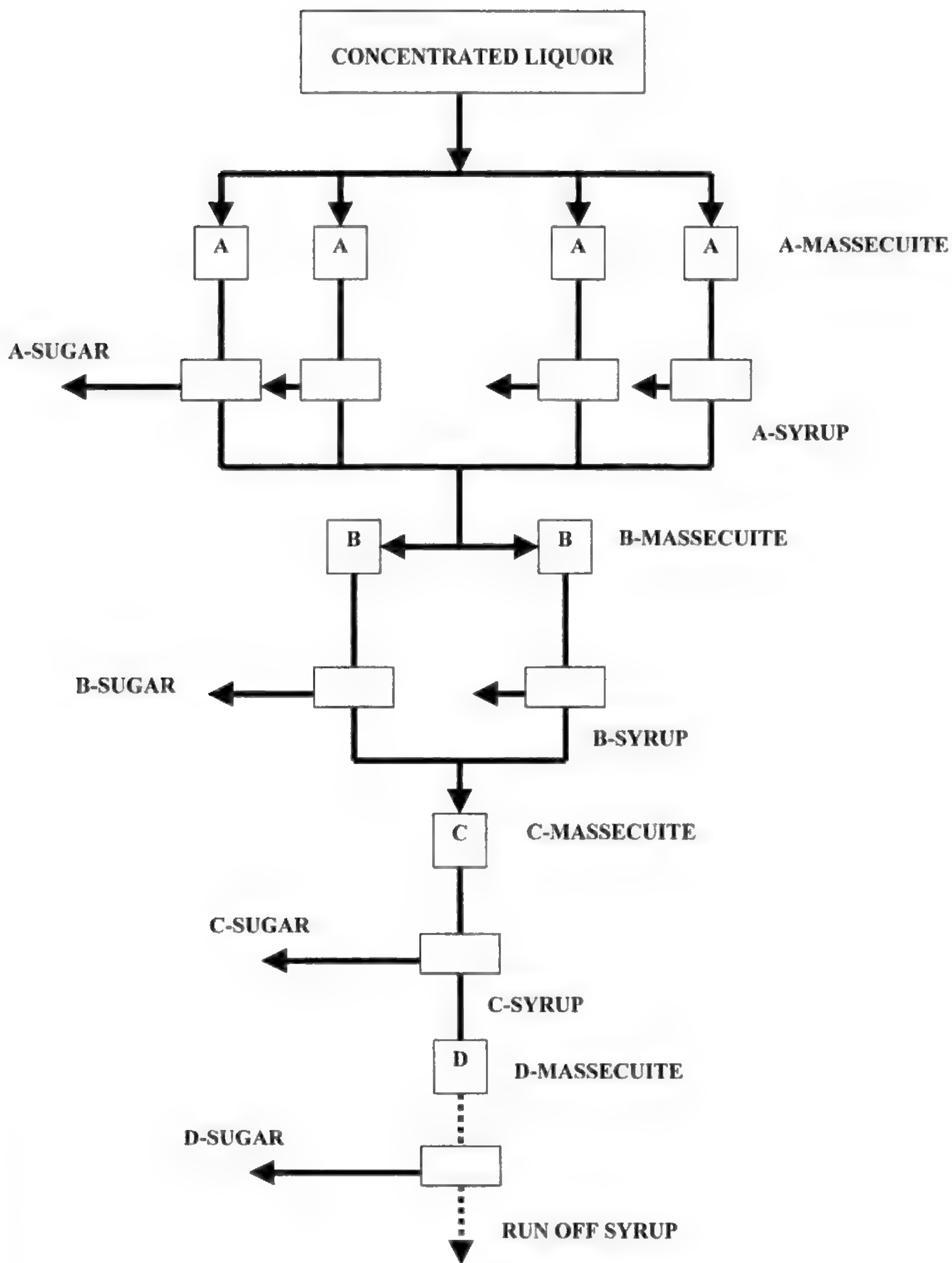


Figure 9 - Massecuite flowchart for the production of refined white sugar

Drying of the sugar subsequent to centrifugation is accomplished with the use of either a rotary drum dryer or a fluidised bed dryer. During the drying process, a small amount of powdered sugar is formed (Puertas, 1961).

Refined white sugar is either bulk packed in 1 and 5 kg bags, or is compressed into cubes.

Production efficiency and quality of refined white sugar

The technological efficiency during the production of refined white sugar is determined on the basis of the quantity of raw sugar used in the manufacture of one unit weight of refined white sugar. Sugar losses during the process are related to:

- Losses during purification and filtration;
- Losses during condensation;
- Losses in the final molasses.

CODEX specifications for refined white sugar are shown in Table13.

Table 13 - CODEX specifications for refined white sugar

Specifications	Values
Polarisation (% min)	99.70
Invert sugars (% max)	0.04
Ash (% max)	0.04
Humidity (% max) *	0.05
Colour (ICUMSA)	60
SO2 (ppm max)	15
Arsenic (ppm max)	1
Lead (ppm max)	0.5

* Recommended value with no specifications.

Consumption of auxiliary materials, fuel and energy

The production of refined white sugar requires the use of a variety of chemical reagents as well as fuel and energy (Tables 14 and 15).

Table 14 - Chemical requirements for the purification of refined white sugar

Purification Stage		
Chemical Product	Phosflotation	Carbonation
Phosphoric acid (kg/tonne rws*)	0.50-0.70	-----
Calcium oxide (kg/tonne rws)	0.35-0.55	10
Amin (kg/tonne rws)	0.2-0.3	-----
Flocculant (kg/tonne rws)	0.01	-----
Hydrogen peroxide (kg/tonne rws)	0.6-1.0	-----
Carbon dioxide in gas	-----	6-8%

*rws = refined white sugar

Table 15 - Consumption of chemical products and utilities for the decolourization process in the production of refined white sugar

Decolourization Stage				
Chemical Products	Powder carbon	Bone char	Granulated carbon	Resin
Carbon (kg/tonne rws*)	4.0-5.0	1.5-1.8	0.6-1.0	-----
Diatomaceous earth (kg/tonne rws)	3.0-4.0	3.0-4.0	1.5-2.1	-----
Resin (l/tonne rws)	-----	-----	-----	0.12
Utilities				
Steam (kg/tonne rws)	1.5-2.0			
Electric energy (kW hour/tonne rws)	60			

*rws = refined white sugar

1.5 Production of amorphous sugar

Amorphous sugar is a refined sugar produced by the treatment, purification and decolourization of either raw or plantation white sugar. It is produced by instantaneous crystallization using open pans, without centrifugation. Although it is similar in colour to refined sugar, it is of a higher ash and invert sugar content. Amorphous sugar is produced primarily in Portugal and Brazil.

Technology for the production of amorphous sugar

The production of amorphous sugar necessitates extensive purification and decolourization of the sugar liquor. The final product incorporates the syrup present in the massecuite. Steps of the process for the production of amorphous sugar are summarized in Figure 10. (Leao, 1974; Valdes, 1989). These include:

- Dissolution of the raw or white sugar to a soluble solids content of 68 to 70 °Brix. If raw sugar is used as the starting material, an affination step is required;
- Increasing the temperature of the liquor to 94°C;
- Purification of the liquor by flotation. Flocculation is facilitated by adding phosphoric acid, lime, surface active agent and air;
- Filtration of the liquor using pressure filters;
- Decolourization of the liquor using either activated carbon or bone char;
- Decolourization using ion exchange resins;
- Evaporation to increase the soluble solids content to 77°Brix;
- Production of a massecuite having a soluble solids content of 93 to 94°Brix by concentrating the liquor in open pans with the use of steam;
- Crystallization of the massecuite in an agitated crystallizer known as a *batideira* which rotates at 30 revolutions per minute over a four to ten minute period;
- Drying of the amorphous sugar to a moisture content of 0.20 percent and cooling to 55 to 60°C;
- Packing and storage.

Alternatively, the liquor can be placed in a vacuum pan and allowed to boil over a 50 minute period, at a temperature of 105 to 110°C, in order to attain a soluble solid content of 92 to 94°Brix. It is then discharged to a vacuum agitated crystallizer. The mass is agitated for seven minutes while decreasing the temperature of the massecuite to 60°C, resulting in the production of sugar having a moisture content of 3 to 3.5 percent (Bento, 1983).

Plantation white sugar has a colour of 250 ICUMSA units. This colour is decreased to 120 ICUMSA subsequent to purification, and is further reduced to 55 ICUMSA after carbon treatment. At the outlet of the ion exchange column during final decolourization it has a colour of only 30 ICUMSA units. At the packing stage, amorphous sugar has a colour of 40 ICUMSA units (Valdes, 1989).

Storage and packing.

Amorphous sugar has a high surface to weight ratio, dissolves rapidly and is very sensitive to changes in humidity owing to its high invert sugar and ash content. The recommended maximum storage time for amorphous sugar is two months. Year-round production of amorphous sugar is therefore generally recommended.

Sugar quality and losses

Major losses in sucrose which take place during the production of amorphous sugar, occur during the filtration process. Some losses also occur during production of the massecuite owing to the temperature of the mass.

The production of amorphous sugar has several advantages over the production of refined white sugar. These include:

- Lower investment and production costs;
- Lower thermal and electric energy consumption;
- Lower personnel requirements for operation and maintenance;
- Higher sugar yields since the liquor is incorporated into commercial sugar;
- Lower equipment (e.g. vacuum pans, crystallizers and centrifuges) requirements;
- Processing of the end liquor is not required.

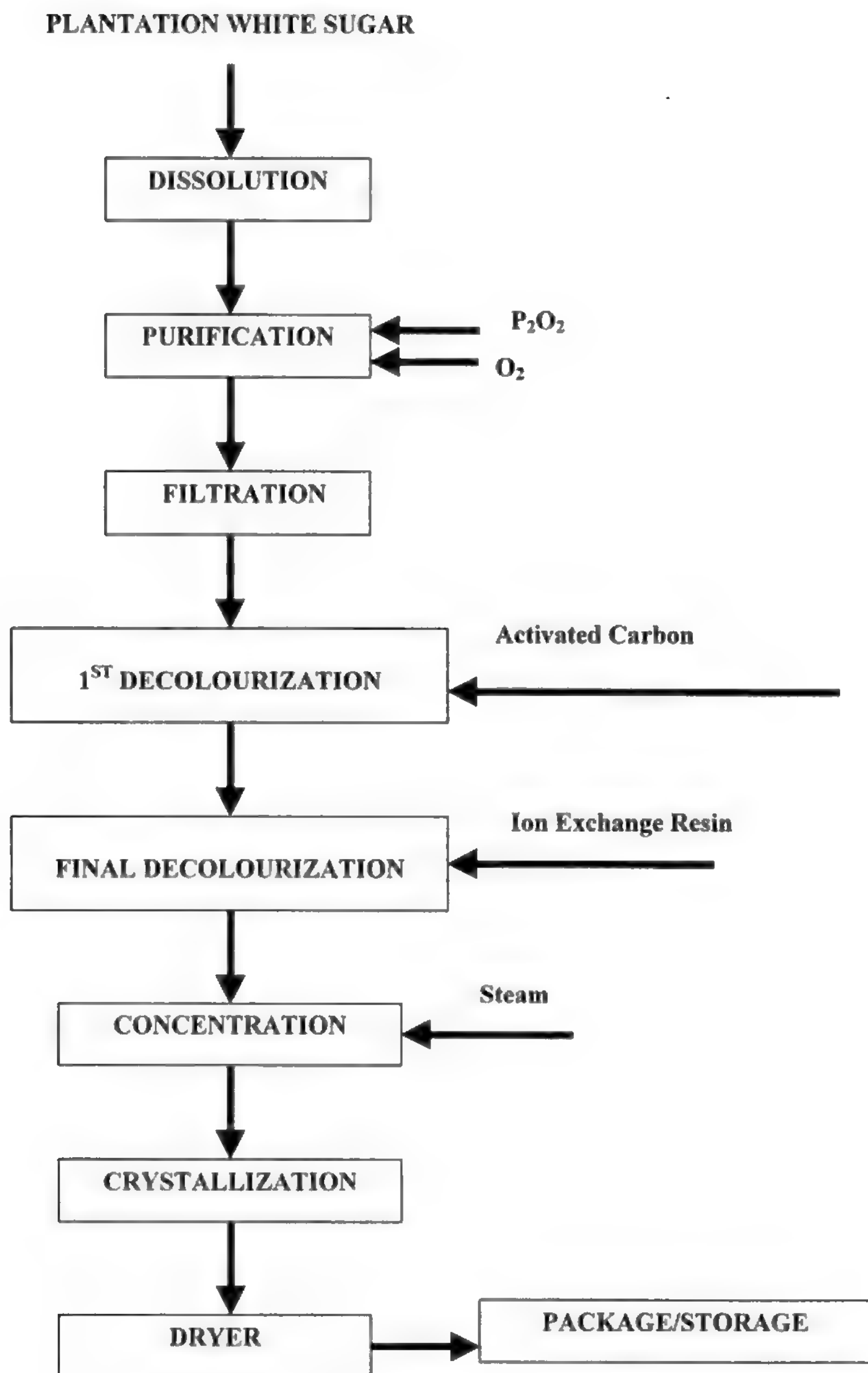


Figure 10 - Flowchart for the production of amorphous sugar

1.6 Production of liquid sugar

Liquid sugar is produced primarily for industrial use. It consists of a solution of sugar of low ash content, in water. Liquid sucrose and invert liquid sugar are the main types of liquid sugar produced. Invert liquid sugar solutions produced include invert sugar syrup, fructose syrup, glucose syrup and special syrups containing coloured components such as caramel. The latter is known as golden syrup and consists of solutions of fructose, glucose and sucrose.

Liquid sugars are generally tailor made to the requirements of the market for which they are produced. Liquid sugar is used in the production of alcoholic and non-alcoholic drinks, in the production of condensed milk, ice cream, jellies, bread and sweets. It is also used as a fermentation substrate in the production of beer.

Technically, the production of liquid sugar offers several advantages over the production of crystalline sugar. Since liquid sugar does not contain any crystals, less power and energy are required for its production. The cost of producing liquid sugar is therefore lower than that of producing granular sugar. Liquid sugar is in addition more easily handled since bags are not required for its handling. Requirements for manual labour in the production of liquid sugar are low, and the sugar can be easily transported and stored. Liquid sugar is however costly to transport, and is highly susceptible to contamination during storage. Steps in liquid sugar production are summarized in Figure 11.

Liquid sucrose

Liquid sucrose is produced either by the dissolution of refined sugar or by the decolourization of purified raw sugar liquor. In the latter case, a decrease in the ash content is recommended. Liquid sucrose is used mainly in the production of condensed milk and ice cream. The main properties of liquid sucrose are summarized in Table 16.

Table 16 - Properties of liquid sucrose

Variables	Liquid Sucrose
Soluble solids (Brix)	65-67
Sucrose (%)	63-65
Invert sugar (%)	2
pH	6.8-7.0
Ash (%)	0.02-0.07
Colour (ICUMSA)	30 max.

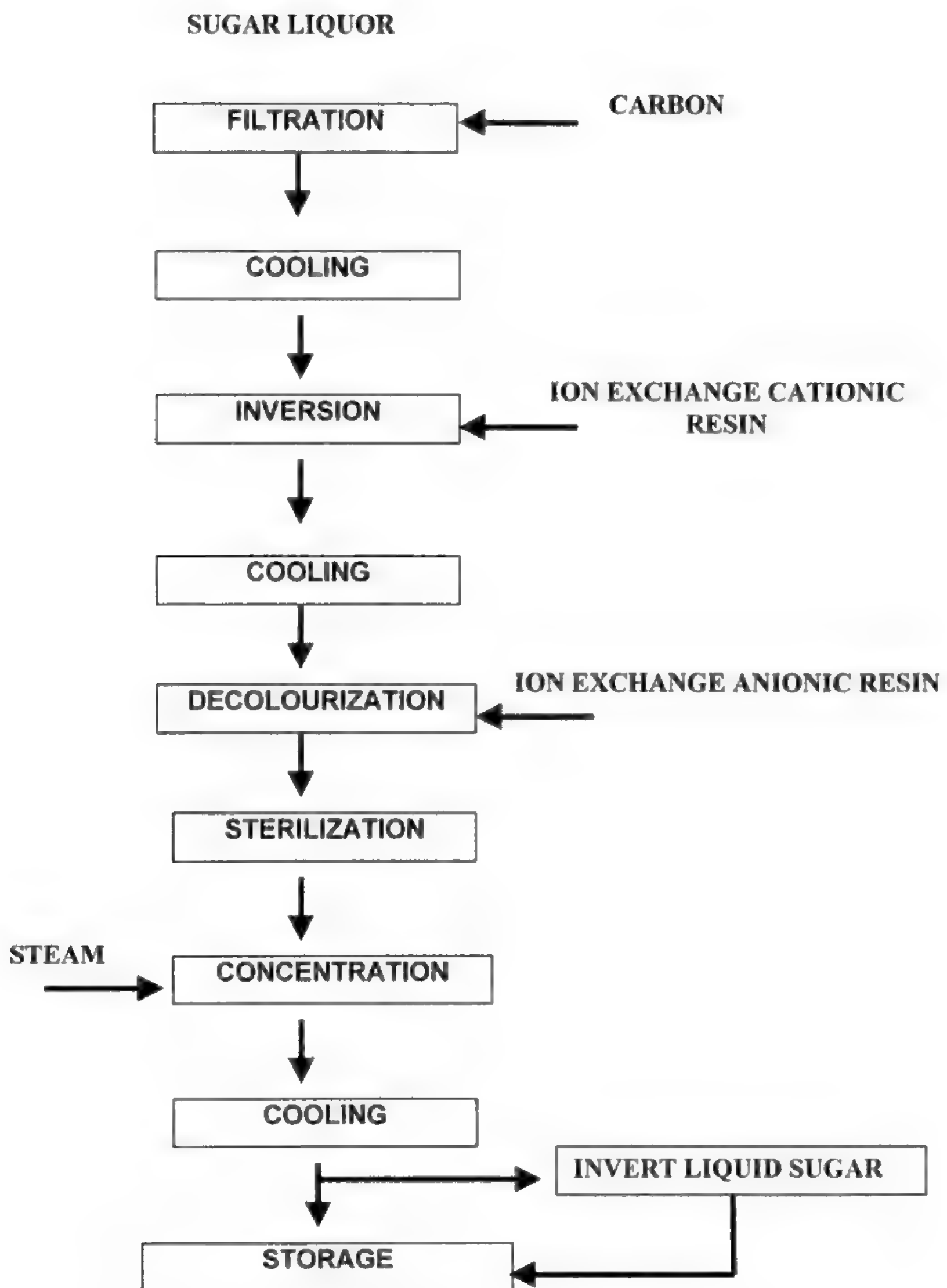


Figure 11 - Flowchart for the production of invert liquid sugar

Production from dissolved refined sugar

Liquid sugar is produced from dissolved refined sugar in a series of steps (Chalmers and Zemanek, 1965):

- Dissolution of the granulated refined sugar in high quality water;
- Heating the solution to 70 to 80°C in order to dissolve the crystals and to sterilize the solution thus formed;
- Automatic adjustment of the soluble solids content to 65.0 to 67.5°Brix;
- Cooling of the liquid sucrose solution to ambient temperature.

Treatment with activated carbon, followed by filtration can be applied in decolourization of the liquor if necessary.

Production from affinated raw sugar liquor

Liquid sugar can be produced from an affinated raw sugar liquor in accordance with the following steps:

- Decolourization of the liquor by activated carbon or bone char followed by treatment with a strong basic anionic resin (if necessary);
- Concentration by evaporation under vacuum at a temperature not exceeding 60°C;
- Cooling to ambient temperature. ($\approx 30^\circ\text{C}$).

Resins were initially used to enhance decolourization with carbon or bone char. Complete decolourization can also be achieved with the use of ion exchange resins. A deionisation step may however be required if the ash content is very high (Fries and Wilson, 1991).

The manufacture of liquid sucrose by the decolourization and treatment of affinated raw sugar liquor offers certain advantages over liquid sugar production by the dissolution of refined sugar. These include lower production cost, since it is not necessary to produce the white refined sugar crystal, lower equipment, energy and manual labour requirements and no packing and storage requirements.

Invert liquid sugar

Invert liquid sugar can be produced either by the dissolution of a refined sugar or by the decolourization of purified raw sugar liquor. It is used primarily in the production of beverages, drinks, jellies, and confectionery goods and as a substrate in the fermentation of beer. The composition of the sucrose component of invert liquid sugar is shown in Table 17 (Galban, *et al.*, 1989).

Table 17 - Characteristics of invert liquid sugar

Variables	Invert Liquid Sugar	
	Type I *	Type II **
Soluble solids (°Brix)	73-75	76-78
Sucrose (%)	35-37	17-19
Invert sugar (%)	40-42	59-61
pH	4.0-4.2	4.0-4.2
Ash (%)	3.0-5.0	0.1-0.3
Colour (ICUMSA)	0	0

* Type I is recommended for the production of soft drinks, jellies, confectionery.

** Type II is recommended for the production of alcoholic drinks.

Source: Cuban Sugar Research Institute Report, (1985).

Production from affinated raw sugar liquor

The production of invert liquid sugar from affinated raw sugar liquor involves the following:

- Affination, purification and decolourization of raw sugar either by carbonation or phosflotation;
- Further decolourization of the liquor using either activated carbon or bone char;
- Pressure filtration of the liquor in order to separate the exhaust carbon;
- Decolourization using strong basic anionic resins (if necessary);
- Inversion by adding either a strong acid resin, an acid solution or with the use of immobilized enzymes;
- Addition of a strong basic resin in order to increase the pH;
- Concentration of the liquor by evaporation under vacuum at a temperature not exceeding 60°C;
- Cooling of the liquor and storage at room temperature (≈30°C).

Production from dissolved white refined sugar

The main steps in the production of invert liquid sugar from dissolved white refined sugar include:

- Dissolution of the granulated refined sugar in good quality water and adjustment of the soluble solids content to between 73 and 78°Brix;

- Heating of the liquor to between 70 and 80°C in order to facilitate complete dissolution and sterilization;
- Inversion by adding either a strong acid resin, an acid solution or with the use of immobilised enzymes;
- Cooling and storage of the invert liquid sugar at room temperature.

Storage

Invert liquid sucrose must have a minimum solids content of 65 to 67°Brix during storage. It is more susceptible to microbial attack than is crystalline sugar and must therefore be kept in clean and sterile vessels, free of microorganisms. Either stainless steel tanks or tanks coated with material that resists corrosion, must be used for storage of the product. In addition, storage tanks must be completely washed with hot water or steam subsequent to their use (Stengl and Zdenka, 1978).

The interior of invert liquid sugar storage tanks, must be equipped with overhead ultraviolet lamps. Air circulating in the upper part of the storage tanks must be cleaned. The syrup can be separated from air during storage, by layering refined mineral oil on its surface. It can be sterilized by circulation through ultraviolet lamps (Gaddie, *et al.*, 1964).

1.7 Production of glucose and fructose syrup

Glucose or dextrose is a sugar that occurs in many different plants and which can be produced from both starch and sucrose. It is used in both food and pharmaceutical applications.

Fructose syrup is produced from sucrose with the use of isomerase enzymes, which convert glucose to fructose. It is used in a variety of food processing applications.

Production of crystalline glucose and fructose syrup

The technology used in the production of crystalline glucose and fructose syrups is dependent on the intended use of the crystalline glucose. The equipment used is the same as that for the production of plantation white and refined sugars. Although other products such as plantation white sugar and decolourized raw sugar syrup have been studied as sources of glucose for the production of sorbitol, refined sugar is generally the raw material used.

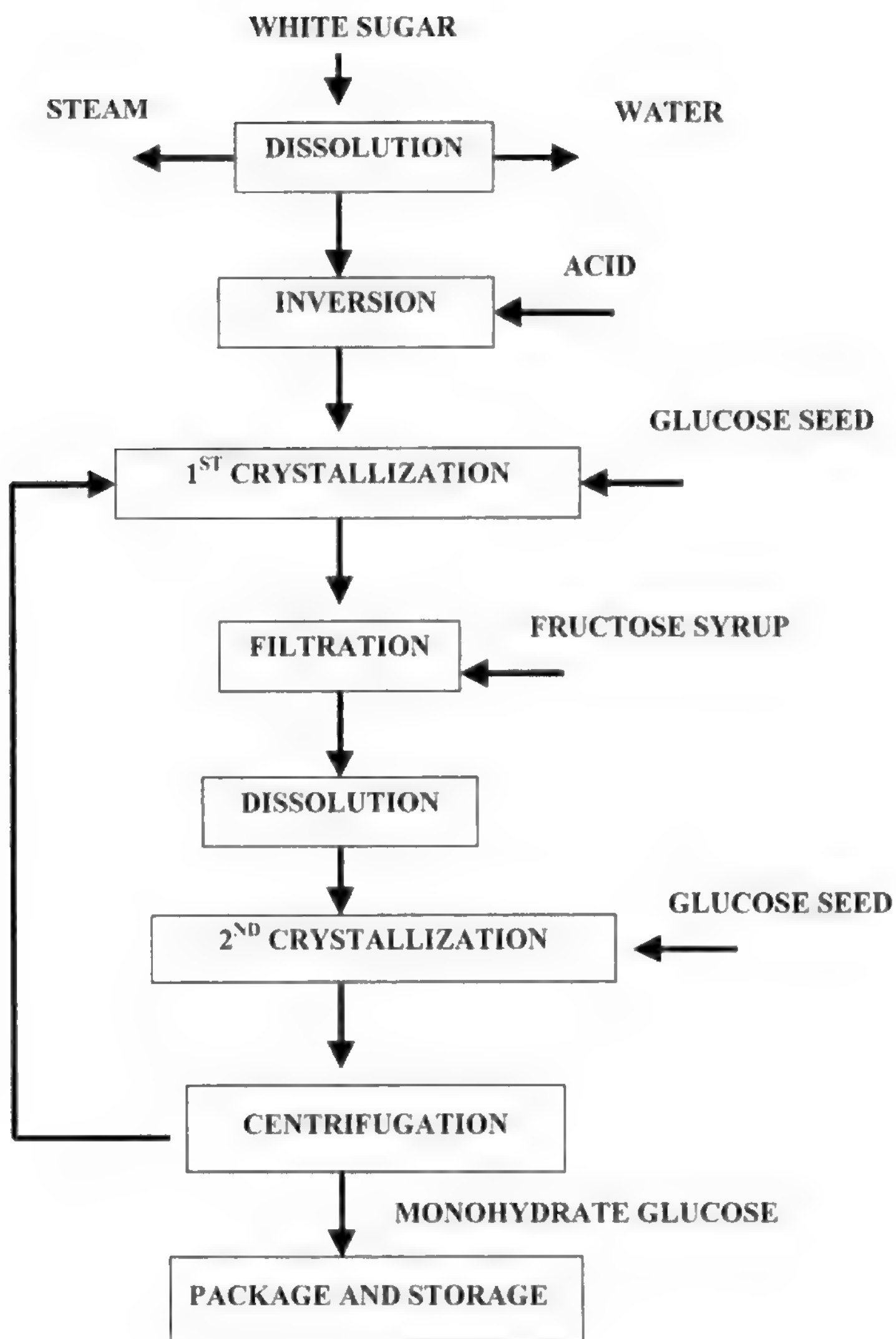


Figure 12 – Flowchart for the production of monohydrate glucose and fructose syrup
(Sources: Fariñas, *et al.*, 1992; Cuban Research Report, 1995)

Production of glucose monohydrate and fructose syrup

An eight-step process (Figure 12) produces monohydrate glucose, which can be used in the production of sorbitol.

The process incorporates the following:

1. *Dissolution* of the refined sugar to produce a liquor having a soluble solids content of 76 to 77°Brix;
2. *Inversion* of sucrose present in the liquor to a minimum level of 95 percent with the use of hot (80 to 90°C) hydrochloric acid;
3. *Crystallization* of the invert sugar by cooling to ambient temperature, seeding with glucose crystals and stirring for 18 to 20 days, in order to attain a 17 to 20 percent crystal yield. Crystallizers used in the production of raw or plantation sugar are used for this process;
4. *Pressure Filtration* in order to separate crystalline glucose from fructose syrup. The glucose crystals obtained require further purification, while the fructose syrup which has a 55 percent fructose content is an end product and sent to storage;
5. *Dissolution* of the glucose mass to a soluble solids content of 74 to 75°Brix;
6. *Crystallization* of the glucose liquor thus obtained by seeding with glucose and stirring over several days in order to ensure transfer of a maximum amount of the glucose present in the liquor to crystalline glucose. A 25 to 30 percent crystal yield is obtained;
7. *Centrifugation* of the crystallized mass thus obtained in a batch centrifuge to obtain purified glucose, which constitutes the end product. The supernatant glucose syrup is concentrated by evaporation and recirculated to the first crystallization step (step 3);
8. *Packing and storage* of the crystalline glucose monohydrate in paper bags and storage in a dry place.

Production of anhydrous glucose powder and fructose syrup

Anhydrous glucose powder is applicable in the production of vitamin C or dextrose solutions for parenteral use. The technology for the production of this sugar involves thirteen steps, the first eight of which are similar to those used in the production of glucose monohydrate. Steps of the process include:

Production of glucose monohydrate (as described in steps 1 to 8 above).

9. *Dissolution* of the crystalline glucose obtained at step 5 to obtain a solution having a 70 percent soluble solids content;
10. *Decolourization* of the glucose syrup thus obtained by mixing with carbon and diatomaceous earth (filter aid), followed by pressure filtration;
11. *Crystallization* of the syrup and seeding with glucose. During this process, the mass is stirred over several days at a temperature of 45°C;

12. Centrifugation of the mass thus obtained in a batch centrifuge to produce crystalline glucose as the end product and glucose syrup, which is concentrated by evaporation and recycled to step 6 in the scheme for the production of glucose monohydrate;
13. Drying of the glucose thus obtained to a moisture content of approximately 0.5 percent and packing in bags.

Yield and characteristics of glucose powder and fructose syrup

Six tonnes of refined sugar are required for the production of one tonne of glucose monohydrate. In the process 6.60 tonnes of fructose syrup are recovered. The composition of glucose monohydrate and fructose syrup is shown in Table 18. The fructose syrup produced in the process has properties similar to those of high fructose corn syrup (HFCS) produced from maize.

On the other hand, in the production of anhydrous glucose, 5 tonnes of refined sugar are produced per tonne of glucose, with 5.20 tonnes of fructose syrup generated in the process.

Table 18 - Composition of glucose monohydrate and fructose syrup

Type of Sugar		
Characteristics	Fructose Syrup	Crystalline glucose
Glucose content (%) Db	37-41	94-95
Fructose content (%) Db	55-59	5-6
Sucrose content (%) Db	4-5	0
Colour (ICUMSA)	400-600	150-200
Humidity (%)	----	13
Soluble solids (%)	73-75	--
pH	2.6-3.0	--

Db: dry base
 Source: Fariñas, (1989).

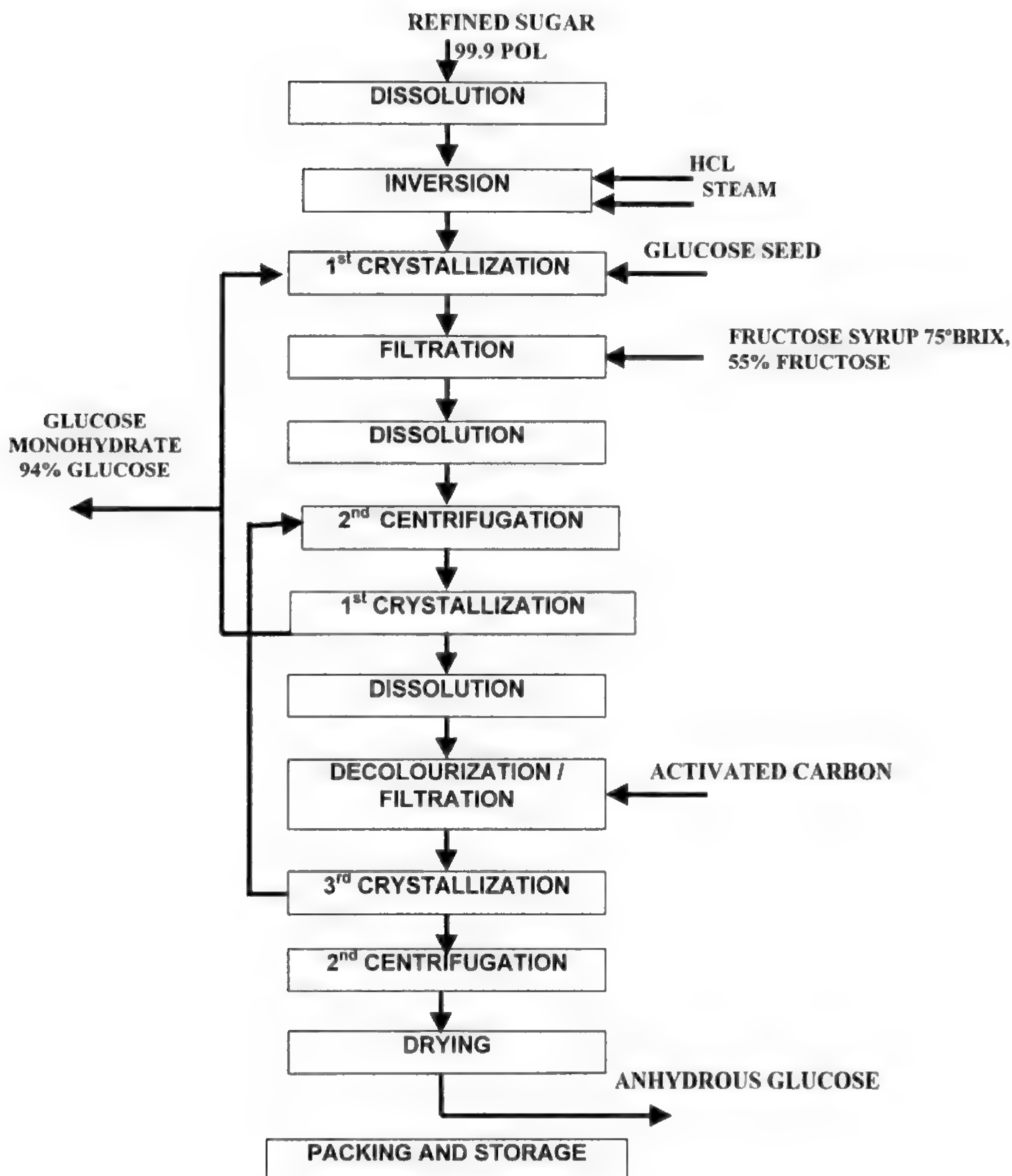


Figure 13 - Flowchart for the production of anhydrous glucose and fructose syrup

CHAPTER 2

BY-PRODUCTS OF CANE SUGAR PROCESSING

Introduction

The term *by-product*, which is common in technological, economic and financial descriptives of the sugar production process, is becoming outdated and is questioned by many specialists in the field. Up to 50 or 60 years ago, raw sugar and plantation white sugar were the only products of the sugar cane industry. Other outputs of the sugar industry which were considered as residuals or wastes included molasses, filter cake (cachaza), bagasse, furnace ash and combustion gases, water overflow from closed evaporators and the condenser pan cooling system, wash waters and cleaning washouts. Disposal of most of these wastes was required. Ethanol and spirit beverages such as rum were the first value added products, prepared from the sugar by-product, molasses.

In the 1960s, special attention was paid by research institutes and sugar enterprises in Cuba, Taiwan and a number of other sugar producing countries, to the development of new products from the by-products of sugar cane processing. Cheaper, more competitive technologies than those already known and established were investigated. These investigations resulted in the utilization of wastes generated from cane sugar processing as raw materials for other industries. Brazil for example developed an integrated industry for the production of sugar and alcohol, which today incorporates the co-generation of electric power for delivery to the national grid. Cuba also developed large installations for the combined production of sugar and particle board from bagasse and for the combined production of sugar and yeast. In addition, Cuba has incorporated the co-generation of electric power and cattle growing with the production of raw sugar.

By-product manufacture offers potential for increasing the profitability of the sugar extraction process through alternative use of juices, which are normally recycled during the sugar production process. Juice, which would normally undergo recycling, might for example be more profitably utilized in the production of torula yeast. Such changes can however only be implemented with new approaches to investment in the sugar industry.

This Chapter focuses on proven products and processes for upgrading sugar cane by-products.

2.1 Cane sugar processing streams for the production of by-products

By-products of sugar cane processing which offer potential for use as raw material inputs in by-product processing include:

- Juice emerging from the crusher or first mill;

- Diluted juice emerging from the exhaust section of the extraction installation;
- Surplus bagasse ;
- Ash produced during the combustion of bagasse;
- Purified or clarified juice;
- Filter cake or cachaza;
- Molasses.

Each of these by-products has attributes, which render it suitable as a raw material for processing into other products. Juice, syrup, and various types of molasses for example, are suitable as carbon sources, as an energy source for fermentation and as animal feed, since they contain dissolved carbohydrate, organic matter, potassium and phosphates. Bagasse and harvest wastes on the other hand are useful as fuels and raw materials for fibre based industries such as paper and fibreboard manufacture and in cattle feeding.

Sugar cane bagasse

Prior to describing bagasse as a raw material for the processing of by-products, it is necessary to detail a morphological description of sugar cane.

Structurally, the sugar cane stalk consists of an epidermis, cortex and the internal structure of the sugar cane stalk, all of which show an apparent continuum. The epidermis is made up of resins, gums, oils and waxes. Its main function is to give the stalk resistance to weathering, by providing impermeability to water and resistance to irradiation from the sun. Sugars and the main components of fibre such as cellulose, hemicellulose and lignin are not present in the epidermis.

The cortex is made up of lignified fibre. It forms an outer ring all along the stalk of the sugar cane and contributes to the resistance of the sugar cane stalk to traction and compression, particularly under windy conditions. The internal structure of the sugar cane stalk on the other hand consists of parenchymatous tissue contained within fibrovascular bundles. The vascular morphology of the fibrovascular bundles allows the transport of nutritional material (sucrose, other sugars and soluble solid constituents of the cane in solution) in the parenchymatous tissue, from the root through the cane stalk to the leaves. Parenchymatous tissue is of an amorphous mechanical constitution.

Bagasse emerging from the mills or diffuser during sugar processing is a heterogeneous mass with a 50 percent moisture content, a soluble solids content ranging between 1.5 and 3 percent, an insoluble solids content ranging between 2 and 3 percent and a cellulose content varying between 44 and 46 percent. Both the fibre and the pith constituents of bagasse are composed of cellulosic matter. The fibre constituent of bagasse consists of fibrovascular bundles, while the pith is composed primarily of parenchymatous tissue, which is of an amorphous mechanical structure. Morphologically, the pith differs from the fibre in that it is vulnerable to traction and shear. The pith content of the cane varies between 2 and 4 percent, depending on the method of harvest and the extent to which the cane is cleaned prior to milling. It is reduced to dust and small particles on milling during the juice extraction

process. Since fibres present in the pith exhibit poor mechanical attributes, they must be eliminated prior to using bagasse as a fibre source for the production of paper and board.

Dry bagasse consists of approximately 50 percent cellulose, 25 to 27 percent hemicellulose, and 20 to 22 percent lignin. Bagasse has a heating value, is easy to access and does not produce an increase in carbon dioxide during the entire course of its production from sugar cane. Bagasse therefore represents an ideal fuel for the future.

Bagasse depithing

Depithing of bagasse, is by no means a simple task. The obvious method of depithing is through separation on the basis of particle size. This method is not however satisfactory in separating parenchymatous materials and other fibres from the bagasse. Another method applied in depithing is separation on the basis of differences in the buoyancy of pith particles and fibres in air and water.

Depithing may be conducted using moist, wet, or dry conditions. Moist depithing is conducted close to the sugar factory on bagasse emerging from the extraction process at a moisture content of 50 percent. Wet depithing may be conducted at the by-product factory. It involves suspending the bagasse in water at a dry solid content of 5 percent. Dry depithing is performed, either after the bagasse is artificially dried to about 15 percent humidity, or after long periods of storage when bagasse attains a stable humidity level. Dry depithing is generally conducted using a rotary drum screen; moist depithing is performed using a mechanical depither, while wet depithing is conducted using a hydropulper.

Over the past 25 years, washing machines, which separate particles on the basis of differences in weight and density, have been applied in depithing. Very good results are reported for the use of this equipment in depithing in that the fibre obtained is of high quality, with a low ash and sand content. Use of this equipment results in relatively few losses due to fibre damage.

Yet another piece of equipment applicable in depithing is the pneumatic separator. This piece of equipment though not frequently used is extremely efficient and operates on the basis of buoyancy differences between the pith and fibre.

Pith particles are of a spongy texture, and are capable of absorbing larger amounts of chemicals than are fibres. In fact they are capable of absorbing four times the amount of solution that can be absorbed by fibre bundles. Pith particles are also of a higher ash content than the fibre bundles. The spongy properties of pith are however problematic in paper and board processing operations.

Bagasse storage

Bagasse production in some countries is seasonal. Bagasse must therefore be stored over the period in which the cane sugar factory is not in operation. Storage of bagasse can however result in quality losses in its fibre constituents. Bagasse may be stored either by packing in bales, in a compressed palletised form or in bulk. The preservation of moist bagasse (50 percent humidity) of a high residual sugar content (2 to 3 percent), against microbial attack, however poses a challenge, since microbial degradation of bagasse results in destruction of its lignocellulosic content, thereby resulting in losses. Storage requirements of depithed bagasse are influenced by the methodology used in depithing.

Moist bagasse (50 percent humidity) emerging from the mill may be directly packed into bales for storage. It may also be dried, depithed, or depithed and dried prior to being packed into bales. Depithing and drying prior to packing into bales is generally preferred since losses due to fermentation are decreased. The size of the bale should allow the escape of gases produced within the bale as a result of fermentation, so as to prevent damage and losses. Although the advantages of drying the bagasse for storage are clear, the advantages of depithing are less conclusive.

Bulk storage is mainly used for the storage of bagasse destined for paper processing applications. Bulk storage involves piling the wet bagasse in mounds up to between 20 and 25 metres high in order to prevent it from being blown away. The application of biological liquors to the pile is helpful in safeguarding against fermentation, while acid and alkaline liquors are useful in initiating the processes, which continue during digestion of the bagasse. Bagasse stored in bulk may be categorized on the basis of the liquor applied in its storage, e.g. biological liquor storage, water storage, acid liquor storage or alkaline liquor storage.

Bagasse may be transported to the storage site either in the solid form or in suspension. A moist system consists of bagasse of high moisture content, transported to storage by a conveyer belt, while a suspension system consists of bagasse suspended in water, transported through a pipe to the storage site.

Sugar cane molasses

Sugar constitutes approximately three-quarters of the total solids content of molasses. Sucrose accounts for approximately half of the sugar content of molasses, while reducing sugars, consisting of approximately equal quantities of D-glucose and L-fructose account for the remainder of the sugar content. The non-sugar constituents of molasses include ash (10 percent), nitrogenous organic matter (approximately 5 percent) and miscellaneous materials (10 percent) which include organic matter, gums, acid and other materials. Final molasses is an excellent raw material for fermentation owing to its high sugar content and probiotic properties, which promote microbial growth.

Filter cake

On a dry basis, filter cake consists of sucrose and reducing sugars (10 to 14 percent), proteins (12 to 16 percent), wax, oil and resins (10 to 14 percent), ash (8 to 12 percent), cane pith (18 to 25 percent), and other substances (25 to 35 percent) (Galvez, *et al.*, 1988).

2.2. Alcohol production

Alcohol is the oldest by-product of the industrial processing of cane sugar. As a derivative of the sugar cane industry, alcohol is produced either as an azeotropic mixture with water, (93 to 95 percent alcohol content) or in the anhydrous form (> 99 percent alcohol). Alcohol is applicable as a fuel for domestic and automotive use and as an industrial solvent.

The production of alcohol involves four essential steps: preparation of the substrate or mash, inoculation with yeasts, fermentation, and alcohol recovery. The preparation stage is dependent on the nature of the raw material. Common sugared streams used for alcohol production are mixed juice emerging from the mills, clarified juice, molasses (A, B or final), and mixtures of clarified juice with syrup.

Preparation of the substrate or mash

Where cane juice is used as the main body of the mash, a process similar to that employed in sugar production clarifies the juice. Milk of lime is added to the juice in order to attain a final pH of 5.5, and the juice is heated to 105°C in order to accelerate the rate of calcium phosphate formation and coagulation of proteins present in the juice. The juice is then sent to a clarifier in order to allow for settling or flocculation of extraneous matter. Clarified juice thus obtained has a solids concentration of 14 to 15°Brix, which may be adjusted to 20°Brix, by mixing with either syrup or molasses (final, A. or B molasses).

With molasses as the main constituent of the mash, fermentation yields are improved due to the probiotic constituents of molasses. Heating of the mash is very important in that it renders the mash free of all types of microorganisms, particularly those, which contribute to undesirable fermentation.

Yeast preparation and inoculation

Microbiologists and fermentation specialists have worked together on the development of yeast strains with characteristics such as stability, high productivity of invertase and zymase enzymes, resistance to osmotic pressure (e.g. osmotic pressures in substrates of 18 to 20°Brix) and high temperatures (36 to 40°C). *Saccharomyces Cerevisiae* is the most widely used yeast in alcoholic fermentation. Either fresh or recycled yeast may be used in alcohol production. The preparation of fresh yeast involves either a four or five stage process.

Preparation of fresh yeast inoculant

Yeast production is initiated from selected yeast strains under aseptic conditions and controlled conditions of pH, temperature, cell concentration, nutrients and total solids content. The yeast is then transferred to a metallic grower maintained under aerobic conditions, following which the grown yeast is transferred through a pipeline to the processing plant. With the exception of the final stage, of cell manipulation and growth, which takes place in a pre-fermenter, remaining cell multiplication and growth of the yeasts takes place in closed stainless steel tanks. Aerobic conditions required for respiration of the cells during growth are maintained by sparger systems located at the bottom of the growth tanks. Air supply to these spargers is filtered through an air filter, which consists of a glass fibre bed enclosed in a metallic cylinder. The filter is maintained aseptic by blowing with steam.

Preparation of recycled yeast inoculant

An alternative method of preparing yeast inoculum for fermentation is through the Melle or Melle-Boinot system. This involves repeated reuse of yeast. At the end of each fermentation cycle, alcohol produced is recovered by centrifugation. The pH of the yeast precipitate recovered in the centrifugation process is then adjusted to 3.0 with the addition of sulphuric acid. The quantity of separated yeast recovered on a dry solids basis, is greater than the initial quantity applied as an inoculum. Excessive amounts of yeast produced are used as cattle feed.

The fermentation process

Fermentation is catalysed by enzymatic activities produced by the yeast inoculum. Invertase enzymes catalyse the conversion of disaccharides such as sucrose which is the main constituent of sugar, to produce monosaccharides, while zymase catalyses the conversion of monosaccharides to carbon dioxide and ethanol. Ethanol production at initial stages of the process is slow due to the high concentration of monosaccharides in the mash and the presence of small amounts of ethanol. The rate of ethanol production however subsequently increases due to zymase activity.

Separation and purification of ethanol

The ethanol content of the product of alcoholic fermentation varies between 5 and 8 percent. This alcoholic product also contains sugars, small amounts of other chemicals such as acetic, propionic and butyric acids produced during the fermentation, minute quantities of mixed amyl alcohols, and esters, in addition to chemicals originally present in the molasses, or cane juice. Ethanol is separated, rectified and purified by distillation. Where anhydrous ethanol is purified for use in industry, a dehydration step is required. Distillation has high-energy requirements owing to the large amounts of water (also referred to as slop stillage or vinasse) which must be condensed during the process.

Economic aspects of ethanol production

Investment costs for an alcohol production plant with a capacity of 60 000 litres per day, which uses molasses as raw material, is distributed among equipment, construction and other costs as follows:

	Percent
Equipment	77
Construction	13
Other costs	10
Total	100

Production costs are as follows:

Raw materials and other additives	68
Salaries	2
Depreciation	7
Others	23

The price of ethanol produced by fermentation fluctuates considerably. The industrial use of ethanol is threatened by the use of synthetic alcohol, which is more economically produced.

2.3 Production of animal feed

The sugar cane industry is the source of a number of by-products, which may be used as raw materials for the production of animal feed. The profitability of using the by-products of sugar cane processing as animal feed is however dependent on a number of factors. Among others, these include the cost of sugar and animal feed, the market possibilities for other types of animal feed, and the location of the sugar factory in relation to the animal farm.

Final molasses is by far, the most widely used by-product of sugar cane for animal feed production, since it is produced in large quantities. Bagasse and some fractions of the pith fraction recovered from depithing installations are also used for cattle feeding in a hydrolyzed form. Sugar cane crop residues such as the tops, green and dry leaves and soil from the mechanically harvested cane are also applicable as animal feed when concentrated in cleaning solutions with 5 percent of the harvested cane.

A number of intermediary products obtained during by-product processing are also applicable in the preparation of animal feed. These include pre-digested bagasse or pith produced during paper manufacture; yeast recovered during alcohol production and slops produced during alcohol distillation.

Torula yeast

Torula yeast (*Candida utilis*) is commonly utilized as animal feed on the basis of its high protein content (> 40 percent on a dry weight basis), high protein quality, biochemical stability and rapid growth rate. This organism is capable of metabolising hexoses, pentoses, and other organic non-sugars such as acids, alcohols and aldehydes.

Torula yeast is produced by fermentation of a carbohydrate source such as molasses, in a fermenter or bioreactor. At the initial stages of the fermentation process, sucrose is converted to reducing sugars, in order to serve as a fermentation substrate. Reducing sugars thus produced, together with those already present in molasses, and an added nitrogen source (ammonium salts) are metabolised by yeast under aerobic conditions created by dissolved oxygen present in the medium, resulting in the production of large quantities of yeast biomass, carbon dioxide, water vapour and heat. During the fermentation process, aeration of the medium is accomplished by blowing large amounts of air into the medium, so as to attain a maximum level of oxygen in the medium. Air distribution within the medium is facilitated by mechanical agitation. Temperature control is also very critical since at temperatures exceeding 35°C, poor growth and reproduction of the yeast results in low biomass yields.

Yeast thus produced is separated by continuous liquid/liquid centrifugation in two stages with inter-stage washing. Yeast cream obtained after the second centrifugation step is concentrated by vacuum evaporation to a moisture content of 23 percent, following which it is spray dried to a moisture content ranging between 5 and 8 percent. The product thus obtained has a protein content of approximately 45 percent, an ash content of 7 to 10 percent, and total carbohydrate content of 20 to 30 percent.

The production of torula yeast can be costly owing to the high cost of inputs (molasses, chemicals, and energy) required by the process. Production costs are however reduced if the starting carbon source is a by-product, e.g. slops of distillation, or by integration of the process with sugar processing.

Yeast recovered from distilleries

Use of the Melle-Boinot system of inoculation in many distilleries enables the recycling and reuse of yeast during alcohol production. Excessive quantities of yeast produced in the process are concentrated and dried for use as animal feed (Anon, 1988).

Bagasse and pith

Ruminants are capable of digesting cellulose, which is a constituent of both bagasse and pith. Digestion of cellulose in the rumen results in the production of useful sugars, which can be used as an energy source. Lignin, the binding agent between cellulosic fibres, however limits cellulose digestibility in the rumen. Chemical or thermal pre-treatment of cellulose weakens the binding effect of lignin, thus improving its digestibility.

Both integral bagasse (i.e. bagasse emerging from the mills) and the pith fraction obtained subsequent to depithing are applicable in use as cattle feed. Integral bagasse is of very low (12 percent) digestibility, while the digestibility of the pith fraction is relatively higher (22 percent) (Noa, *et al.*, 1985). The digestibility of integral bagasse can however be improved either by chemical or thermal treatment.

Chemical improvement of bagasse digestibility

Chemical improvement of the digestibility of bagasse involves treating the pith with sodium hydroxide, followed by blending it with molasses and urea. A flow chart of the process is shown in Figure 14. The level of sodium hydroxide added is very critical in that sodium hydroxide is responsible for loosening fibres within the fibre bundles. Inadequate levels of sodium hydroxide are ineffective, since lignin is not adequately degraded at low sodium hydroxide levels, to allow for penetration of liquids in the rumen. Excessive levels of sodium hydroxide are however harmful to the animal.

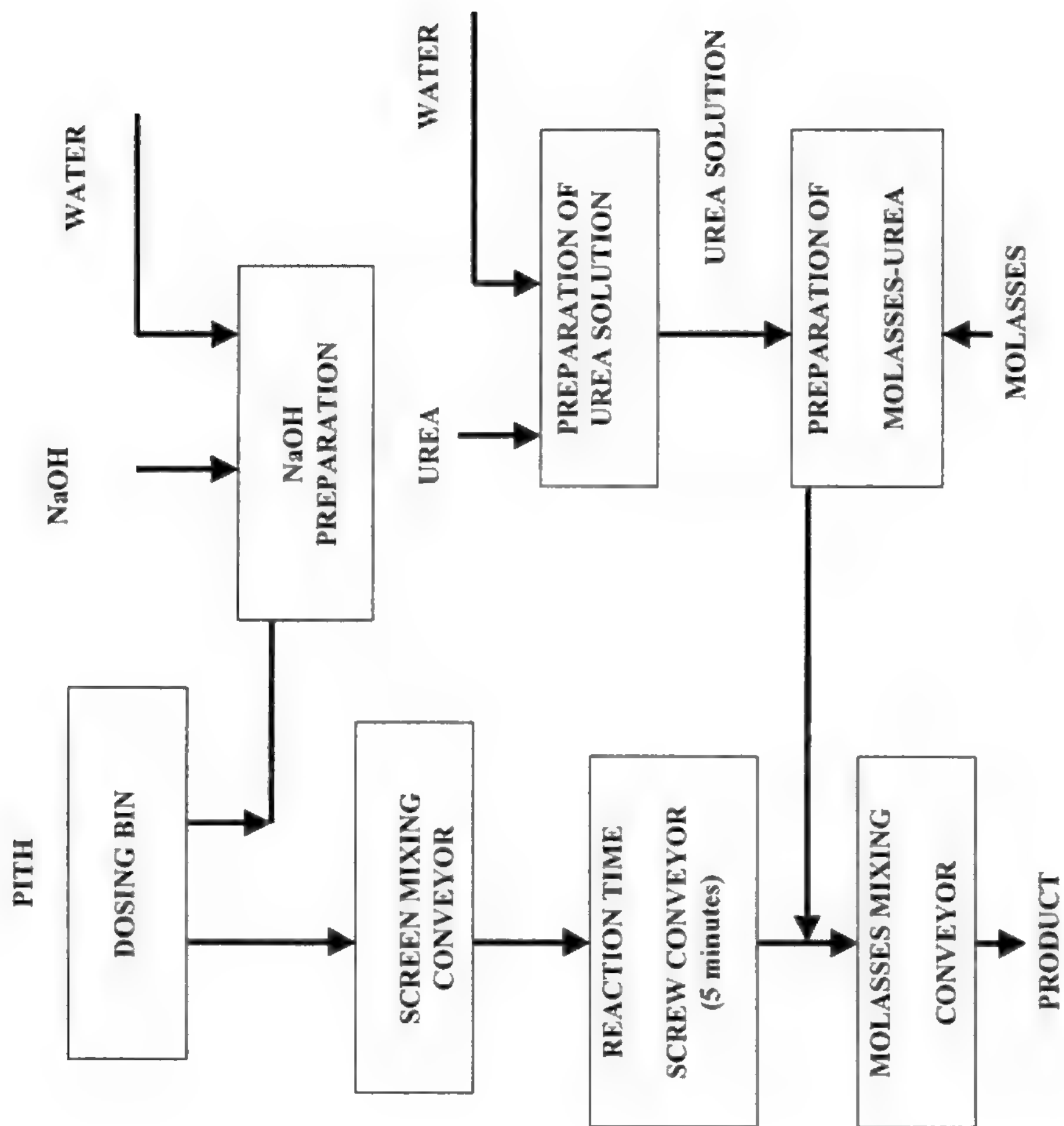


Figure 14 – Flowchart for the production of chemically pre-digested pith feed

Thermal improvement of bagasse digestibility

Thermal processing is an alternative to chemical processing for increasing the digestibility of integral bagasse. Use of this process is becoming more widespread, owing to the increasing cost of sodium hydroxide. During thermal processing bagasse undergoes rapid expansion at a relatively high temperature. This results in the production of acetic acid by acetyl radicals generated in the hemicellulose, which promote acid hydrolysis of the cellulose.

Thermal processing may be performed either at low (170⁰C) temperature and pressure over a period of 15 to 30 minutes, or at high temperature (210 to 220⁰C) and pressure (2.1 to 1.8 Mpa), over a three to five minute period. Low temperature and pressure treatment of the bagasse results in up to a 60 percent increase in digestibility, while high temperature and pressure treatment results in a 55 percent increase in digestibility. In both cases, acetyl radicals freed as acetic acid, cause a decrease in the pH of the bagasse.

Pre-digested bagasse is of a high-energy value from a metabolic point of view, but is of poor palatability. Its palatability can however be improved by mixing with molasses. A true protein carrier such as yeast, soybean, or cotton meal along with a nitrogen carrier such as urea or ammonium sulphate may also be added. Table 19 shows a typical animal feed blend produced using pre-digested bagasse.

Table 19 - Typical animal feed formulation produced using pre-digested bagasse

Product	(kg/day)	%
Pre-digested bagasse	13.00	55.85
Cane (ground)	3.60	15.96
Corn (grain)	1.70	7.18
Cotton seed meal	1.60	6.78
Molasses	0.74	3.19
Urea	0.15	0.60
Ammonium sulphate	0.02	0.08
Salt (plus other minerals)	0.10	0.39
Water	2.30	9.97
Total	23.21	100.00

Source: Alternatives using sugar cane for energy and animal feed. (International Symposium, Dominican Republic, 1987).

Protein rich molasses

Protein rich molasses is prepared by blending molasses of 70⁰Brix, with torula yeast cream, having a solids content of 23 percent. The blend is adjusted to a protein content ranging between 15 and 16 percent and a solids content of 38 percent. The composition of this product is shown in Table 20.

Table 20 - Composition of protein rich molasses

Dry matter, %	38-40
Gross protein, %	15-16
Metabolisable energy,(MJ/kg)	12.6
Reducing sugars *	61-62
Ashes (%)	5.1-5.3
Calcium(%)	2.1-2.3
Phosphorous	1.0-1.5

* Partial inversion of the sucrose either by acidic or enzymatic hydrolysis is necessary

Equipment costs constitute about 60 percent of the investment cost, in the production of protein rich molasses, while construction accounts for about 33 percent. Approximately 85 percent of production costs are consumed by raw materials

Enriched dehydrated molasses

This product is generally sold either as a hygroscopic powder, or in the form of blocks. It is manufactured by an exothermic reaction, between milk of lime and final molasses. Yeast cream is then added, following which the product is mixed and subsequently dried in a rotary drum dryer. The composition of enriched dehydrated molasses is shown in Table 21.

Table 21 - Composition of enriched dehydrated molasses (percent)

Dry matter	92
Total reducing sugars	38
Protein	18
Ashes	10-14
Calcium	3.5

Equipment costs account for approximately 60 percent of the investment requirements for the production of final molasses. Raw materials and additives account for 82 percent of production cost.

2.4 Production of pulp and paper

Paper is a finished product of the pulping process. Paper has been produced commercially using bagasse as a raw material for more than half a century (Noa Silverio, *et al.*, 1991).

Pulp production

Pulp is an intermediate product obtained during paper manufacture. It is produced by the mechanical, thermal or chemical treatment of raw materials, such as wood, bamboo and bagasse. During pulp manufacture, both lignin and hemicellulose levels are reduced.

Pulps are generally produced via a two-stage process. At the first stage, which is a chemical process, lignin and some hemicelluloses are degraded, while loosening of the fibre

bundles occurs. At the second stage, which is mechanical, fibre bundles are separated into individual fibres by a process termed delignification. Delignification may be accomplished either with or without chemical pre-treatment. Partial delignification for the production of semi-chemical pulps may be accomplished by light chemical treatment, at low temperatures, while an advanced degree of delignification is obtained by treatment at higher temperatures. Delignification at high temperatures however results in low pulp yields.

Semi-chemical pulps are used in the manufacture of corrugated paper, newsprint and cultural paper. These pulps are capable of producing a paper having a high surface brightness and whiteness.

Production of mechanical pulp from bagasse

Bagasse is similar to softwoods, in that it is of low resistance, opacity and brightness. Bagasse pulps offer advantages in printing quality, while showing lower basic weight. During mechanical pulping, the bagasse is embedded in hot water at 80°C for two hours prior to refinement of the pulp.

Although mechanically produced bagasse pulps are of acceptable quality, many specialists are of the opinion that mechanical treatment of bagasse must be preceded either by chemical or combined chemical and thermal treatments. A process for the production of chemi-mechanical pulp was developed at the Cuba-9 Research Institute in Cuba. This process involves chemical and thermal pre-treatment of the pulp in order to condition it prior to mechanical treatment. In this process, depithed bagasse having a fibre content of the order of 85 percent is mixed in a specially designed mixer-impregnator, with a hot dilute solution of sodium hydroxide. The moisture content of the pulp is adjusted in a disc press to a consistency of 20 to 30 percent, following which the pulp undergoes refinement via a two-stage process, resulting in a moisture content of 10 to 20 percent.

Pulp thus obtained is further refined via a two stage screening process, whereby the accepted fraction is cleaned in a three cyclones system. The raw pulp fraction is bleached by treatment with hydrogen peroxide in a descending bleaching tower, followed by washing with a SO₂ solution to attain a brightness of 52 to 54 percent. A flow chart of the process along with a simple material balance is shown in Figure 15.

Equipment costs account for 50 percent of the total investment cost for producing chemical pulps, while building and construction costs account for approximately 25 percent. Components of production costs include investment costs (22 percent), bagasse (20 percent) electric power (23 percent) and chemicals (15 percent).

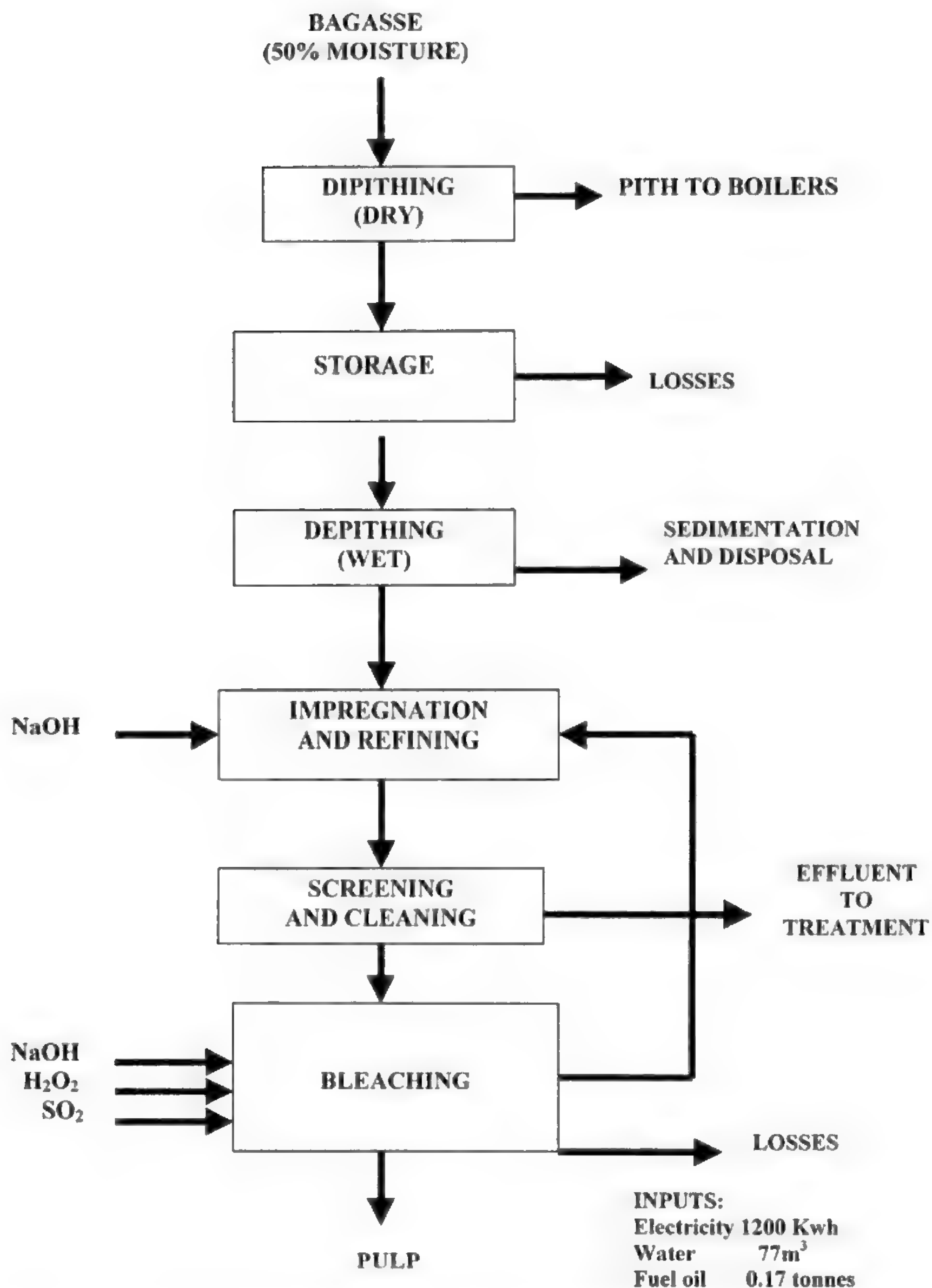


**Figure 15 – Production of chemi-mechanical pulp by the Cuba-9 process
(Galvez, *et al.*, 1988,)**

Production of chemical pulp from bagasse

Chemical pulps are generally produced from bagasse via the soda process. These pulps are used in the manufacture of cultural paper (printing, writing, bond and continuous forms), and for the manufacture of tissue and Bristol board. Soda pulps and sulphate pulps are referred to as alkaline pulps. Sulphate pulps are processed using a blend of sodium hydroxide and sodium sulphide. Although quite similar to soda pulps, the characteristics of sulphate pulps, make them somewhat less popular in use.

Steps involved in the production of chemical pulps include moist depithing of the bagasse to a fibre content of approximately 85 percent, followed by depithing in suspension. The depithed bagasse then undergoes digestion with steam under pressure (7.5 kg/cm²) over a period of 10 to 15 minutes (Galvez, *et al.*, 1988). The digested bagasse is washed with the aid of rotary vacuum filters, screened with vibratory screens and cleaned with the use of hydro-cyclones.

Pulps thus produced may be bleached in two to four stages, either by individual treatment with chemicals such as chlorine, hypochlorite, peroxide, and chlorine dioxide or by treatment with combinations of these bleaching agents. Bleaching is followed by extraction with sodium hydroxide. The physical characteristics of chemical pulps are shown in Table 22.

Table 22 - Characteristics of chemical pulp prepared from bagasse

Density (kg/m ³)	690
Tear index (mNm ² /g)	5.2
Burst index (kPa/m ² /g)	5.2
Tension index (Nm/g)	61.8
Brightness (%)	87.0
Yield (%)	61.7

Source: Galvez, *et al.*, (1988)

Incorporation of additives such as oxygen and anthraquinone into alkaline (soda) pulping has been shown to improve both the properties and yields of the pulp. Pulping with oxygen does not however improve the properties of bagasse pulps, since iron present in the pulp has been shown to increase its viscosity.

The addition of anthraquinone, at levels varying between 0.05 and 0.1 percent on the other hand, has been shown to increase yields and lower chemical consumption in soda pulping. Characteristics of chemical pulps produced with the incorporation of anthraquinone are shown in Table 23. Chemical pulp produced with anthraquinone is similar to soda pulp. It is sent to a storage tower, following which it is bleached. A material balance for the production of soda chemical bagasse pulp is shown in Figure 16.

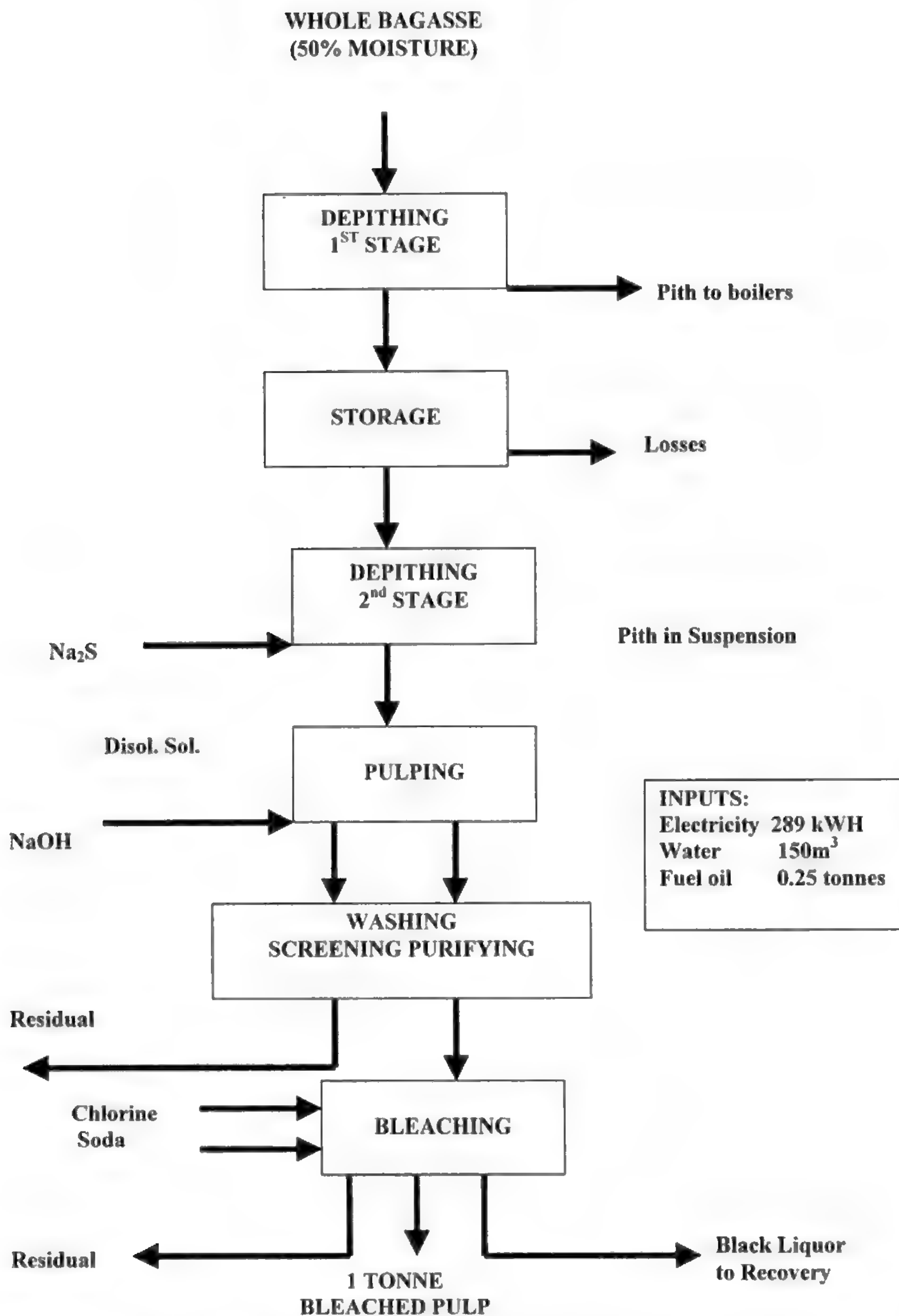


Figure 16 – Flowchart of chemical bagasse pulp alkaline process

Table 23 - Characteristics of chemical pulp produced from bagasse with the incorporation of anthraquinone

Density (kg/m ³)	713
Tear index (mNm ² /g)	7.3
Burst index (kPa/m ² /g)	4.4
Tension index (Nm/g)	51.7
Brightness (%)	89.5
Opacity (%)	80.5
Yield (%)	64.0 to 68.0

Paper from bagasse pulps

Various types of papers of acceptable or competitive quality are produced from bagasse pulps (Table 24).

Table 24 - Bagasse pulps used in various applications

Final Product	Pulp	Inclusion, %
Printing and writing	Chemical, bleached (soda)	70 - 90
Copy paper, manifold	Chemical, bleached (soda)	70 - 80
Bristol board, white or coloured	Chemical, bleached (soda)	70 - 80
Tissue and domestic	Chemical, bleached (soda)	75 - 80
Wrapping, glazed on one side	Chemical, unbleached	70
Liner board	Chemical, unbleached	50 - 70
Bags, multi-layer, (plane)	Chemical, unbleached	50 - 60
Bags, multi-layer, (spread)	Chemical, unbleached	60 - 70
For bags	Chemical, unbleached	40 - 60
Board for corrugating	Semi-chemical, unbleached	80 - 90
Grey board	Semi-chemical, unbleached	70 - 80
Newsprint	Mechanical	42 - 55
	Semi-chemical	22 - 35
	Chemi-mechanical	85 - 90

Source: Galvez, *et al.*, (1988)

Production of Newsprint paper from chemi-mechanical bagasse pulp

Newsprint must be of good printing quality, low price, and have both high opacity and high mechanical strength in order to withstand the tension in modern, high-speed newsprinting presses. Desirable properties of chemi-mechanical pulps for use in newsprint applications are summarized in Table 25 (Galvez, *et al.*, 1988).

Table 25 - Properties of chemi-mechanical bagasse pulps for newsprint applications

Basic Weight, kg/m ³	480-510
Tension index Nm/g	32-37
Tear index (mNm ² /g)	3.5-4.2
Brightness %	52-54
Scattering coefficient	43-47
Opacity (%)	88-92

Source: Galvez, *et al.*, (1988)

A material balance for the production of newsprint from chemi-mechanical bagasse pulp is shown in Figure 17. According to this material balance, 3.4 tonnes of bagasse are required for the production of 1 tonne of paper. Subsequent to chemi-mechanical treatment, the bagasse pulp is blended with chemical wood pulp and mechanical wood pulp. This blend constitutes the total fibrous base of the paper. The blended pulps are transferred to a mixing tank, where in the course of mixing, brokens from the paper machine are added. The blended pulps are refined, following which chemical reagents and other products such as resins are added to enhance the resistance of the paper to liquid penetration. Resins are added in combination with alum in order to control the pH, while colorants and fillers such as kaolin are added to increase opacity. The blended pulp containing the additives is conditioned to produce a paste, which is fed into a forming machine.

Within the wet section of the paper machines, sheets are formed and most of the water is removed from the paste, leaving the already formed sheet with a 20 percent dry matter content. Further dewatering takes place by pressing, resulting in a sheet having a 35 to 40 percent dry matter content. Finally, in the drying section, the paper is dried to a 92 to 95 percent dry matter content by heat transfer through rolls.

Installations for producing paper, are generally capital intensive. The main elements of investment cost include equipment (50 percent) and construction (22 percent). Main elements of production cost include pulp and electricity.

Production of printing and writing paper from bagasse soda pulp

Writing and printing paper must be of good quality for printing, have good ink absorption, surface resistance and smoothness, opacity, brightness, porosity and dimensional stability. Main characteristics of writing paper are shown in Table 26.

Table 26 - Characteristics of writing paper

Basic Weight, (g/m ²)	60
Density (kg/m ³)	751
Tension index (Nm/g)	55
Tear index (mNm ² /g)	44
Brightness (%)	81
Opacity (%)	82

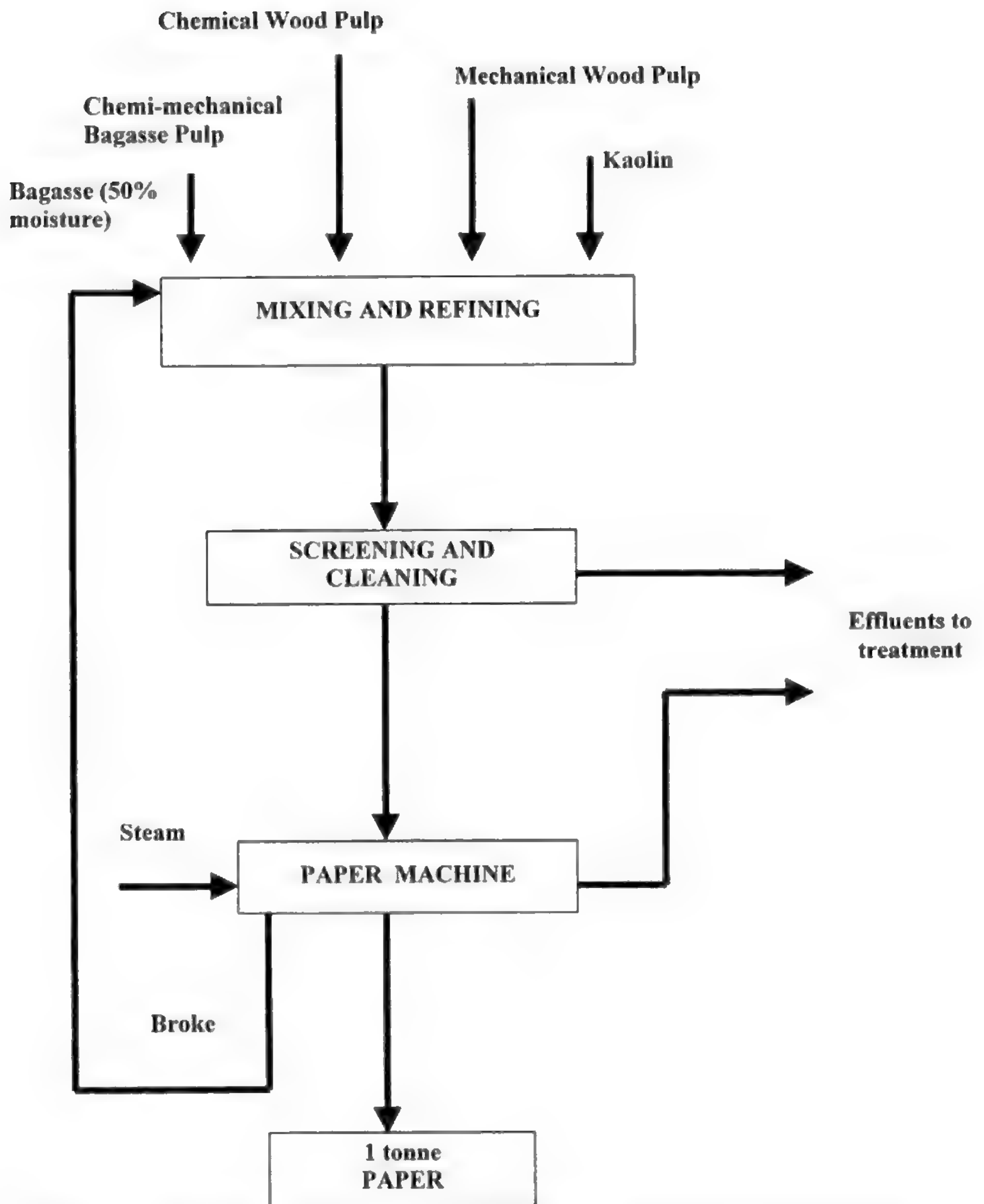


Figure 17 – Flowchart of the production of newsprint from chemi-mechanical bagasse pulp

Bagasse pulps for writing and printing paper are mainly produced from chemical (soda) pulp. Technically, the production of printing and writing paper involves blending refined bagasse pulp with refined wood pulp. The blended pulps are then mixed with the other additives, such as dyes, resins, alum and filler (kaolin). The consistency of the mix thus obtained is then adjusted following which it is screened, cleaned and sent to the head box of

the paper machine. The sheet emerging from the press has a 7 percent moisture content and is sent to a calendar for smoothing. It is finally wound on to a commercial reel.

Figure 18 shows a flowchart of the process for the production of writing and printing paper from chemical alkaline pulp. The production costs of a plant of this type are distributed as summarized in Table 27 (Galvez, *et al.*, 1988).

Table 27 - Distribution of production costs for the production of printing and writing paper from bagasse soda pulp

	%
Whole bagasse, 50 % moisture	14
Chemicals	7
Wood pulp	12
Salaries	4
Other expenses	26
Depreciation	37

Production of Printing and writing paper from bagasse chemi-mechanical pulp

Since chemi-mechanical pulp is of high opacity than are chemical pulps it can be used in relatively smaller proportions than chemical pulps in the production of writing paper. A major drawback in the use of chemi-mechanical pulps is their tendency to assume a yellow colour with time. Characteristics of writing paper produced from chemi-mechanical pulp are shown in Table 28.

Table 28 - Characteristics of writing paper produced from chemi-mechanical pulp

Basic weight, (g/m ²)	58.5
Density (kg/m ³)	644
Tension index (Nm/g)	31.7
Brightness (%)	18
Opacity	89.2
Ashes(%)	15.4

A flowchart for producing writing paper from chemi-mechanical pulp is shown in Figure 19. Wood pulp (long fibre) must be added at a level of approximately 25 percent.

The cost of producing chemi-mechanical pulp is approximately 10 percent lower than that of producing bagasse chemical pulp.

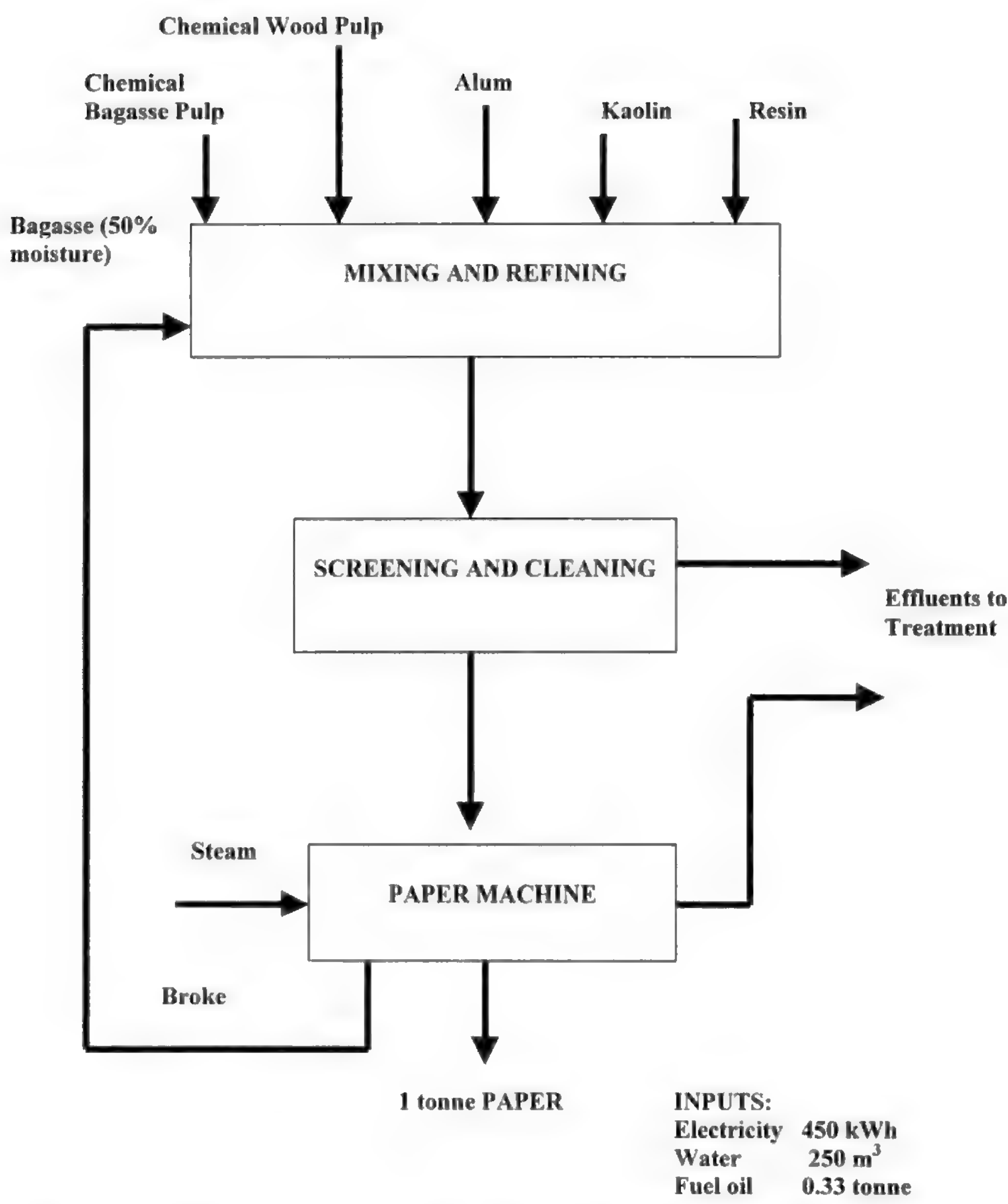


Figure 18 – Flowchart for the production of printing and writing paper from chemical pulp

2.5 Production of agglomerated products

Agglomerated products consist of materials of vegetable origin, bound in a solid almost continuous medium by an agglutinating agent. Artificial resins, derived materials, or even minerals such as Portland cement may be incorporated into agglomerated products. Particle board and fibreboard, which are both used as a wood substitutes, are agglomerated products.

Although fibreboard is generally produced from wastes obtained in the industrial processing of wood, a fairly large amount of fibreboard is produced from cereals, straw and sugar cane bagasse. Particle and fibreboard differ with respect to the methodology used in preparation of the fibrous material. Fibrous material used in particle board preparation is mechanically treated, while that used in the production of fibreboard is treated either by thermal, chemical or mechanical means (Noa Silvero, *et al.*, 1991).

Particle board

The production of particle board involves depithing, followed by grinding and drying. A material balance for the production of particle board is shown in Figure 20.

Ground particles are dried and classified on the basis of their relative sizes. Table 29 shows the particle dimensions of a typical board. During drying, the humidity of the particles is reduced to between 1 and 4 percent, in order to create conditions conducive to gluing, formation and pressing. Over-drying must be avoided in order to prevent electrostatic problems, dust pollution, risks of fire, damage in the border of the formed mat and other detrimental conditions.

Table 29 - Particle dimensions (mm)

Layer	Thickness	Width	Length
Outer	0.15 - 0.3	0.5 - 1.0	<10
Inner	0.30 - 0.7	1.0 - 1.5	<20

Gluing is perhaps the most costly operation in the production of particle board, since the cost of the binding agent (resin) accounts for approximately 30 percent of the cost of the board. The quality of the product is greatly influenced by the quality of the resin and the uniformity of its application. Urea formaldehyde resin is the most widely used gluing agent, though melamine urea formaldehyde resin and phenol formaldehyde are also used. The latter two are more expensive than urea formaldehyde resin, but phenol formaldehyde is recommended where increased resistance to weathering is desired. Natural products derived from wood, particularly tannins mixed with phenol resins, have also been employed as gluing agents.

In 90 percent of the factories, in which urea formaldehyde is employed as a gluing agent, other additives such as ammonium chloride and sodium hydroxide (catalysts) and paraffin emulsions (water repellent) are mixed with the particles. These additives either impart special characteristics to the board, or control the speed and quality of the chemical reactions taking place in the press. Pentachlorophenol provides protection against fungal attack, while inorganic phosphates, borax or ammonium salts have a fireproofing effect. These additives are separately prepared from gluing agents and then thoroughly mixed. The

viscosity of the mixture must be carefully controlled in order to attain the desired penetration of the mixture into the particles.

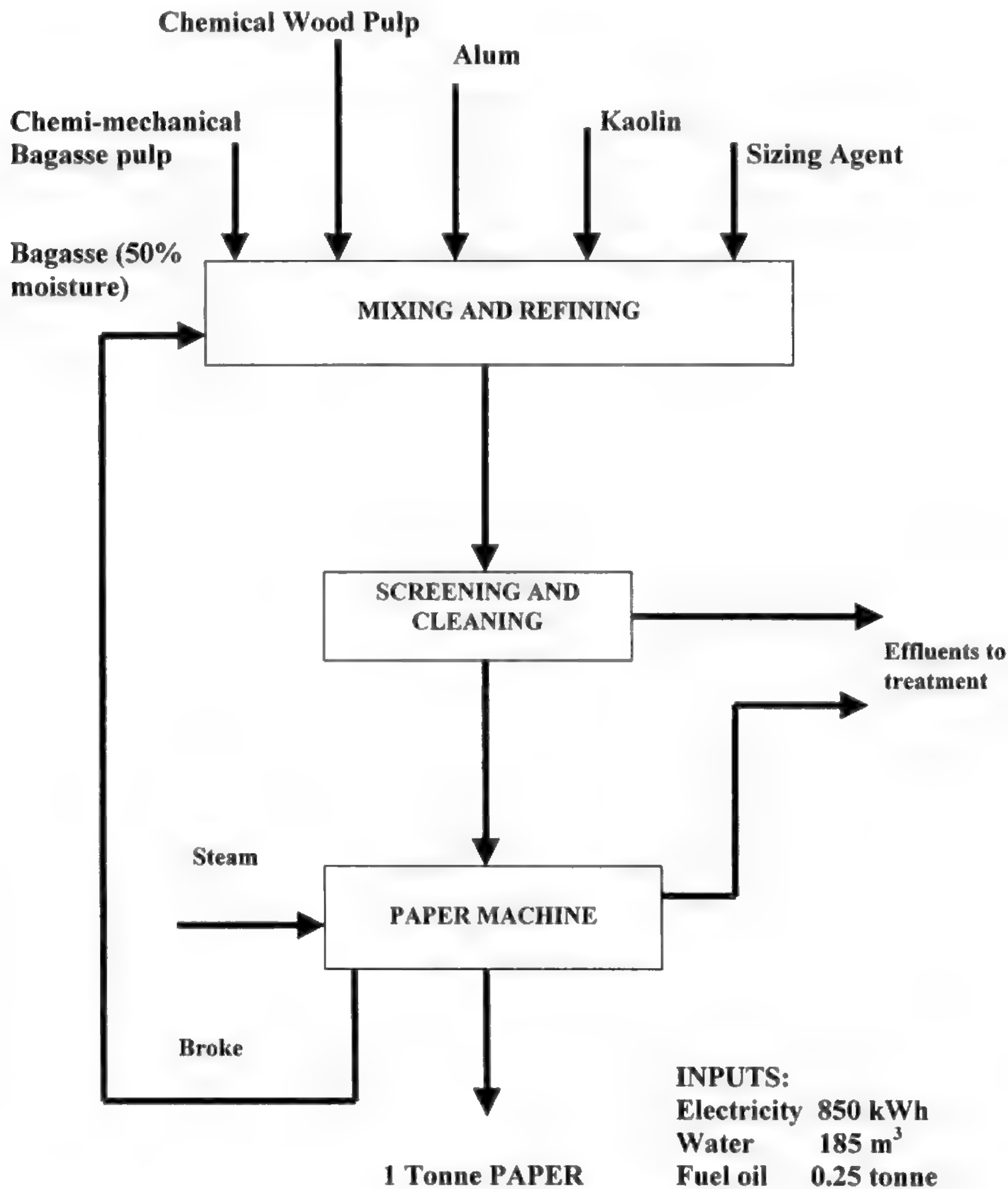


Figure 19 – Flowchart for the production of printing and writing paper from chemi-mechanical pulp

For the production of multi-layer boards, the mixture is added to the particles by separating the material going to the inner layer from that going to the outer layers. Outer layers require the addition of larger amounts of mixture than do inner layers. At the forming stage, a uniform, homogenous mat of particles is formed either mechanically or pneumatically, or using a combination of mechanical and pneumatic techniques. The mat thus produced is pressed, following which the boards undergo finishing in order to bring them to the designed final dimensions, and to complete polymerization of the resin and polishing of the surface. Polymerization is accomplished by allowing the boards to remain under ambient conditions over a seven-day period.

Fibreboard

During fibreboard production, fibrous material is subjected to thermal, chemical and mechanical treatment. All of these processes facilitate the softening of lignin, thereby allowing the separation of its constituent fibre bundles. Separated fibre bundles then undergo cross-linking whereby they stick together.

Due to its fibrous nature and low density, bagasse is a good material for producing medium density fibreboard. Bagasse provides both lightness and good mechanical behaviour in the product. A layout of the material balance for fibreboard production is shown in Figure 21. The first step of the process involves pulp preparation, using mechanical, chemi-mechanical or thermo-mechanical processes. The pulp thus produced is refined in order to obtain fibres of the appropriate dimensions. Chemical agents may then be added in order to enhance the mechanical resistance of the board. Phenol resins and asphalt emulsions, improve the quality of the board, while paraffin increases its water repellency. Other chemical agents are also incorporated in order to avoid bacterial or fungal attack. The pH of the mixture must be very well controlled in order to guarantee the flocculation of gels around the fibres.

The board may be formed either by wet or dry processing. In wet processing, the mat is formed with the fibres suspended in water. Wet processing results in inter-cross linking of the fibres giving the board good mechanical properties. The main drawback of the wet process lies in the requirements for large volumes of water and high investment costs.

In the dry process, on the other hand, dried fibres, with the incorporated additives are pneumatically led over a travelling mesh using suction through the fibres in order to force mat formation. The mat thus obtained is pre-pressed without heating prior to being transferred to the hot press. Hot pressing of fibreboard is done either by wet or dry pressing. Wet pressing, gives a board, which is smooth on only one surface, while dry pressing produces fibreboard which is smooth on both surfaces. Subsequent to heat pressing, boards are trimmed, adjusted in size, length and width, and subjected to re-humidification to almost the equilibrium water content. Fibreboard quality is then improved by painting with a thin film of drying oil and heat-treating.

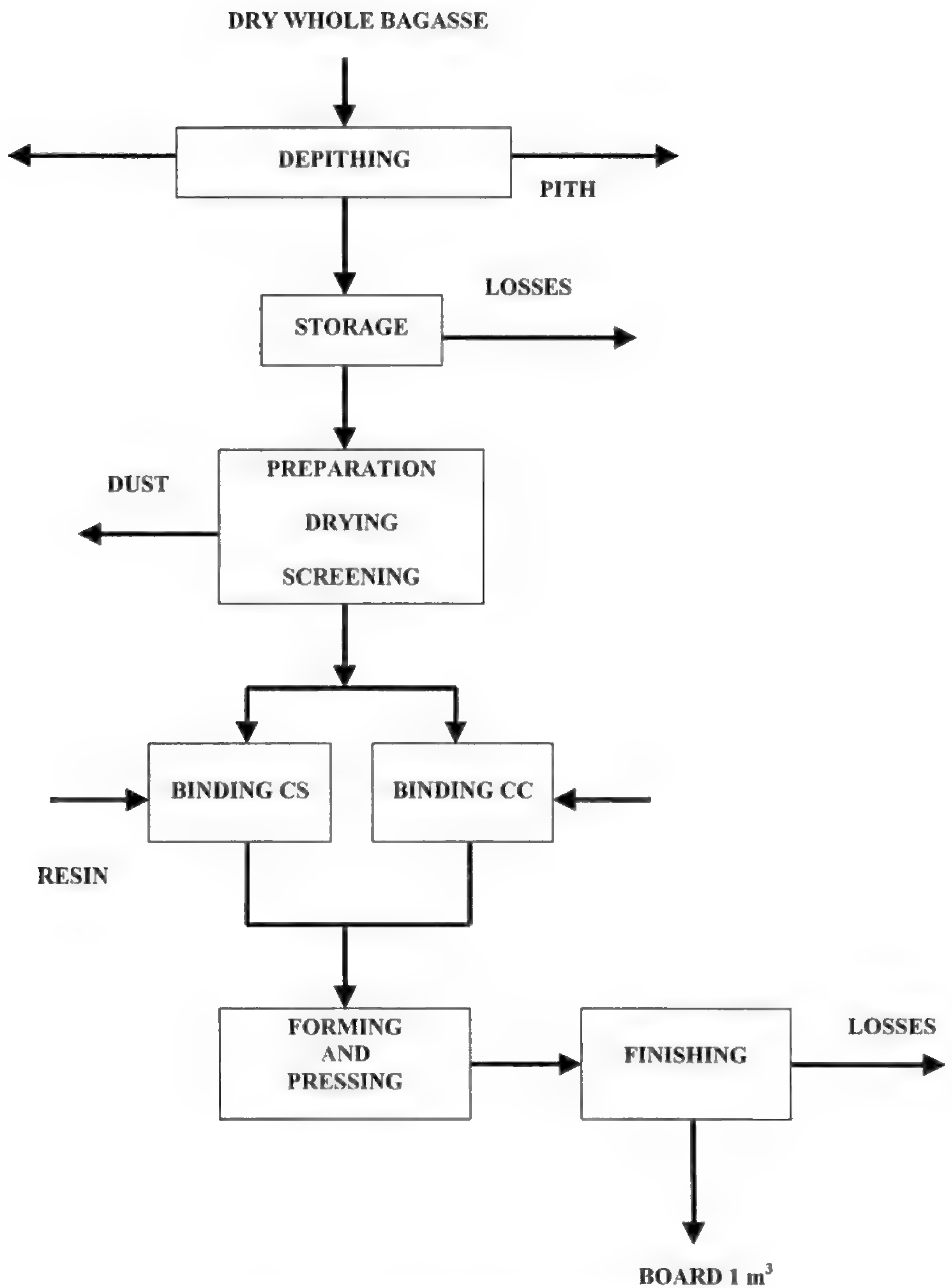


Figure 20 – Production of bagasse particle board

Characterization of fibreboards on the basis of density

Fibreboards may be classified on the basis of the raw material from which they are produced, the type of process used in their production and on the basis of their application in use. Density and thickness are the two internationally accepted parameters for the classification of fibreboards (Table 30).

Table 30 - Fibreboard classification on the basis of density

Type of board	Density (kg/m ³)	Thickness (mm)
Low density	250 to 400	3 to 25
Medium density	400 to 800	10 to 25
High density	>800	2 to 9

Low density fibreboard

Low-density fibreboard is also known as an insulating board. Due to its low density fibreboard does not show high mechanical resistance. It however has good acoustic and thermal insulation properties owing to its porosity. Synthetic or natural resins may be incorporated into the production of low-density fibreboards. Paraffin may also be added to improve water repellency and mechanical behaviour. Properties of low-density fibreboards are shown in Table 31.

Table 31 - Physical and mechanical properties of low density insulating board

Density, kg/m ³	250 to 400
Breaking modulus, Mpa	1.5 to 5.5
Elasticity modulus, Mpa	178 to 880
Traction strength, parallel to fibre, MPa	1.5 to 3.5
Traction strength, perpendicular to fibre, MPa	0.07 to 0.17
Absorption of water (24 h, 20 ⁰ C, %)	15 to 60
Swelling in water (24 h, 20 ⁰ C, %)	12 to 20
Thermal conductivity, kcal/mh ⁰ C	0.035 to 0.056
Acoustic absorption, %, (at 522 Hz)	50 to 85

Medium density fibreboards

A medium density fibreboard (MDF) is used as floorboards in construction applications, and in the ornamental covering of walls. The smooth surface of these boards allows them to be coated with materials such as paper and veneers.

MDF is produced by a dry process. MDF has exceptional mechanical and physical characteristics and has become a strong competitor of particle board produced by the dry process. Properties of MDF boards are shown in Table 32.

Table 32 - Physical and mechanical properties of MDF board

Density, kg/m ³	650 to 800
Breaking modulus, Mpa	25 to 30
Elasticity modulus, Mpa	2 000 to 2 500
Traction strength, perpendicular to fibre, MPa	5.0 to 6.5
Swelling in water (24 h, 20 ⁰ C, %)	<10
Surface roughness (mm)	<30

MDF board can be used in the production of furniture. Its low resistance to bending limits its use for shelving applications.

High-density fibreboard

High density fibreboards are usually known as hardboards, and are produced at a thickness of up to 9 mm. They are produced either by wet, wet/dry or dry processes. High-density fibreboard produced by the wet process is smooth on only one surface. If they are produced either by the wet/dry or dry processes are however smooth on both surfaces.

High-density fibreboard is used in the production of flat doors, in the ornamental covering of walls, in ceilings, packing cases and as a complementary material for furniture production. Its quality is strongly influenced by the use of additives, such as paraffin, synthetic or natural resins, oils, etc. Boards prepared by the dry process require a minimum of gluing agent such as phenol resin, for quality improvement. Physical and mechanical properties of hardboards are summarised in Table 33.

Table 33 - Physical and mechanical properties of hardboards

	Standard Board	Oil Impregnated and Heat Treated
Density, kg/m ³	900 to 1 050	1 020 to 1 060
Breaking modulus MPa	30 to 55	45 to 70
Elasticity modulus Mpa	2 800 to 5 600	5 600 to 7 000
Traction strength, parallel to fibre, MPa	21 to 40	45 to 55
Absorption of water (24 h, 20 ⁰ C, %)	10 to 30	8 to 20
Thermal conductivity, kcal/mh ⁰ C	0.13	0.15

Boards produced using inorganic binders

Fast setting Portland cement is the most widely used inorganic binder in board production. Magnetite and gypsum are also used in board production. In bagasse-cement boards, the lightweight and insulating properties of the fibre are combined with good mechanical characteristics, and resistance to fire, weathering, fungi and insects imparted by the cement. An important characteristic of board produced by inorganic binders, is its density which may vary between 350 kg per cubic metre and 1 350 kg per cubic metre.

Sugars have a retardant and sometimes inhibitory effect on the setting of Portland cement during the production of boards with inorganic binders. Desugaring of bagasse is therefore required prior to its incorporation into the process. Desugaring can be accomplished by proper depithing.

The technology for producing bagasse-cement boards is similar to that used in the production of particle board, with a few additional operations. Steps in the process include depithing, storing, conditioning (grinding), classification, mixing of the particles with cement, forming and pressing. Additional operations include setting, ageing, weathering and trimming.

A material balance for the production of bagasse-cement boards is shown in Figure 22. Cement and a mixture of additives is brought into contact with fibres in special mixers. In this operation separate mixtures are used for the inner and outer layers of the boards.

In the forming operation, a mixture of particles and additives is deposited over metal platens, following which platens are taken to the press where the mat is pressed to the desired thickness. Clamped platens are passed through chambers at a temperature of 60 to 80⁰C for 6 to 8 hours in order to facilitate setting of the cement. The boards are stored for a further 20 days in order to allow complete setting of the cement. At the end of the setting process, boards are exposed to a weathering out process at defined humidity and temperature, using special chambers in order to attain an equilibrium humidity. Edges of the boards are trimmed and eventually sanded on both surfaces. Properties of bagasse cement boards are shown in Table 34.

Table 34 - Properties of cement boards

Density, kg/m ³	1 250 to 1 500
Thickness, mm	10
Flexion strength, MPa	8.0 to 12.0
Traction strength, perpendicular to surface, MPa	0.3 to 0.4
Swelling in water, thickness (24 hours)	1.2 to 2.3

Over 60 percent of investment cost required for producing bagasse cement board is consumed by equipment costs. Cement accounts for 40 percent of production cost, while bagasse accounts for 22 percent.

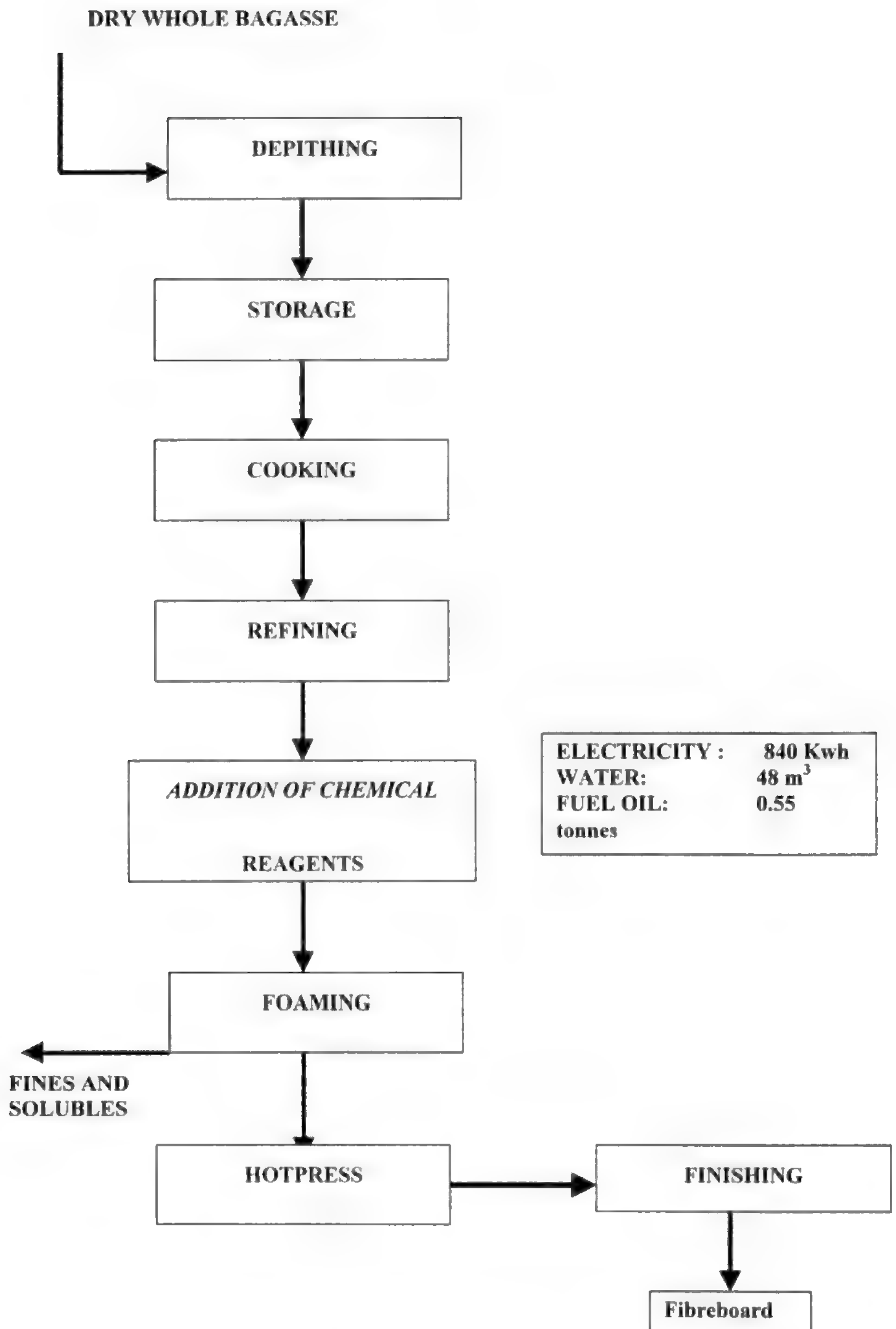


Figure 21 – Flowchart for the production of bagasse fibreboard

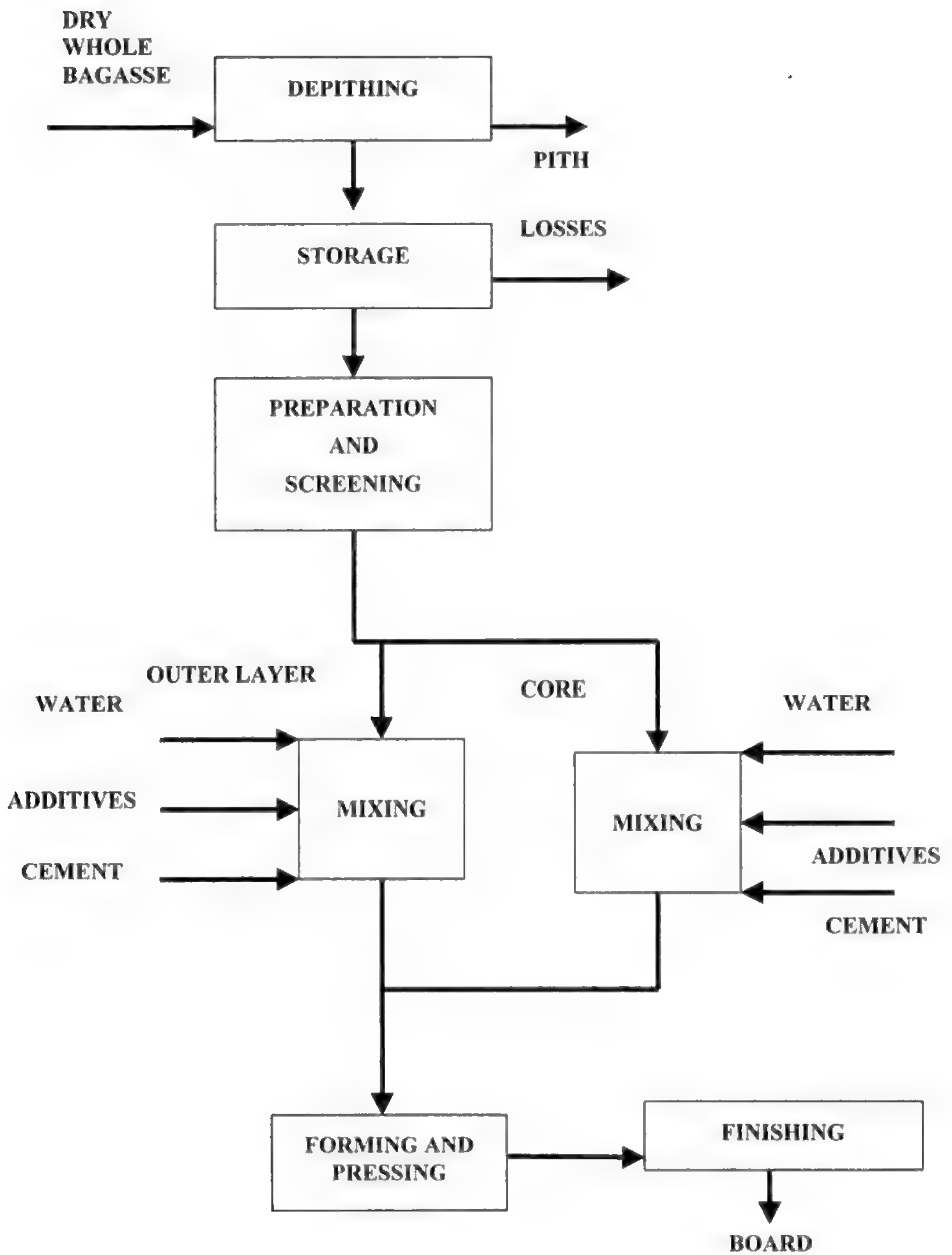


Figure 22 – Flowchart for the production of bagasse cement boards

CHAPTER 3

FUEL AND ENERGY PRODUCTION FROM SUGAR CANE BIOMASS

Introduction

Both fuel and renewable energy are obtainable during the production of sugar from sugar cane. Filter cake is applicable as a substrate for the production of biogas and fertilizers, while alcohol can be produced from either final molasses or mixed juices. Sugar cane crop residues (SCCR) are applicable in the generation of electric power. These residues are also capable of increasing the thermal efficiency of the sugar factory, while leaving surplus bagasse available for other uses (Valdes, *et al.*, 1996).

3.1 The energy potential of the sugar cane agro-industry

Both solar energy and fossil fuels are utilized in the cultivation and harvest of sugar cane. Fossil fuels are used in the sowing, cultivation, harvest and transportation of sugar to the factory. On an energy basis, sugar cane however offers a quantity of biomass that yields 15 times more energy than the fossil fuel used in its production (Prado, 1965).

The energy potential of sugar cane biomass can become a reality through the use, perfection or development of the following resources:

- Use of (SCCR), residual fibre from the extraction plant, cane bagasse and/or sugar cane of high fibre content for fossil fuel substitution;
- Increasing the efficiency in the steam generation plant in order to obtain a surplus of bagasse;
- Increasing the generation and/or cogeneration of electric energy and/or decreasing energy consumption of the sugar process, in order to obtain surplus energy;
- Increasing the efficiency of steam usage in the sugar process in order to obtain surplus bagasse;
- Use of sugar and alcohol residuals to produce biogas for domestic and social food preparation and purification of this biogas for use in metal cutting and transportation;
- Continued studies into the gasification of sugar cane biomass for the production of electric energy and steam.

3.2 Fuels from sugar cane biomass

The primary objective of the sugar industry is to produce sugar and molasses. This industry is however also capable of delivering fuel and thermal or electric energy after satisfying its energy requirements. Bagasse and sugar crop residuals (SCCR) represent two solid renewable fuels that are cyclically produced over short periods. Between 2.3 and 2.5 million tonnes of bagasse and SCCR are obtained as by-products from the production of one million tonnes of sugar. These by-products represent a global quantity of 800 000 tonnes of a non-renewable fuel.

Sugar cane crop residues (SCCR)

The part of the sugar cane above the ground, in the sugar cane field, consists of dry and green leaves, tops and the stalk. Only the stalk is required for sugar cane production. Sugar and fibres present in the stalk are adequate for satisfying all of the energy requirements of a raw sugar production process. Leaves and tops, which constitute the SCCR, have similar weight proportions in the plant. Although tops contain juice of low purity, their use in sugar manufacture is not recommended since they increase the non-sugar content, while increasing sugar losses in the final molasses.

SCCR are used for animal food, as fuel for domestic and social uses, as industrial fuel and for the production of compost, furfural, table boards and other secondary applications. SCCR may also serve as a potential renewable fuel, which can be used for either the generation or cogeneration of electricity. Fuel produced by SCCR is similar to that produced by bagasse in terms of carbon content, humidity and hydrogen content.

Characteristics of SCCR

SCCR consists of green and dry leaves and cane tops in similar proportions. Over three million tonnes of renewable fuel can be produced from the SCCR derived from one million tonnes of sugar cane. SCCR accounts for 28 percent of the plant in the field at harvesting. The physical composition of the SCCR of cane in the field prior to cutting is shown in Table 35, while the chemical composition of SCCR residues is summarized in Table 36.

Table 35 - Composition of the SCCR of cane in the field prior to cutting

Samples	Tops (%)	Leaves and straw (%)	SCCR (%)	Clean cane (%)
Mean	8.44	19.74	28.18	71.82

Source: Betancourt, (1968)

Table 36 - Characteristics of SCCR

Parameters	Tops	Green Leaves	Dry Leaves	Average
Carbon (%)	42.11	43.41	41.76	42.20
Hydrogen (%)	6.25	6.38	6.26	6.29
Humidity (%)	76.79	66.21	8.85	46.11
Value (kcal/kg)	4 319	4 401	4 339	4 340
Ashes(%)	-	-	-	6-10

Sources: Ripoli, *et al.*, (1991); Aguilar, *et al.*, (1990); Zanzi, (1993).

Although burning increases the efficiency with which cane is harvested, while decreasing its EM content, it is disadvantageous in that it adversely affects the availability of fuel derived from SCCR and has an unfavourable environmental impact in that it releases, CO₂ to the atmosphere. Table 37 compares the effect of different harvest systems on the EM of cane.

Table 37 - Effect of the harvest system on the EM content of cane

Source	Type Cane	Extraneous Matter
		(Ratio of the cane processed)
Dry cleaning centre	Green	6.3
	Burnt	4.4
Method of cutting		
Mechanized	Green	12.9
	Burnt	8.4
Manual	Green	2.5
	Burnt	2.4

Source: Valdes, (1993)

Separation of SCCR from cane

Mechanical and manual methods

SCCR can be separated from cane in the field by either hand cutting, mechanical harvesting or by separation in a dry cleaning centre. A flowchart of the processing of sugar cane and residues at a dry cleaning centre is shown in Figure 23.

Separation of the SCCR at the dry cleaning station has the advantage of:

- Concentrating it in one place for manipulation;
- Enabling it to be cut in particles of uniform size;
- Allowing it to be transported to the sugar factory by tractors, trucks or railroad wagons;
- Making it unnecessary to collect SCCR from the field.

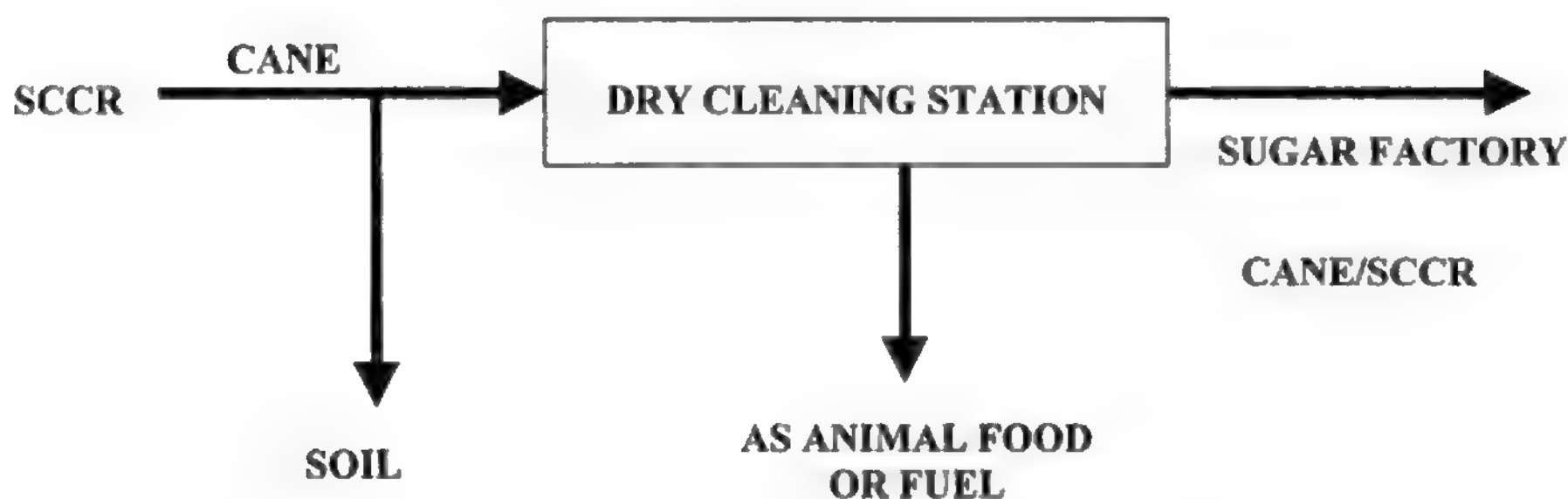


Figure 23 – Flowchart of the processing of sugar cane and residues at a dry-cleaning centre

Heating

Separation of SCCR with the use of a furnace installed at the inlet of the sugar factory is currently under investigation. Furnaces are generally located at the cane conveyor before the shredder. The SCCR portion of the cane undergoes combustion in the furnace, following which the cane undergoes water washing in order to eliminate ash and residues.

The advantages of using the furnaces for the separation of SCCR include:

- Requirements for simpler cane cutting equipment;
- Steam can be produced for factory requirements;
- Elimination of the major EM component;
- Dry cleaning of the cane is not required.

The major disadvantage is that increased capacity is required for transporting the cane to the factory.

Preparation of SCCR

SCCR residues left in the field as cover do not pose any problems with respect to germination of the sugar cane plant in dry weather. Germination is however delayed under humid conditions. These residues require preparation and transportation prior to use in the boilers of the sugar factory.

Separation of SCCR at dry cleaning stations results in a product of low bulk density ($25\text{--}40\text{ kg/m}^3$) which must undergo further treatment, prior to being transported to the sugar factory for use in steam generation. Densification of SCCR in the form of bales of low-density (215 kg/m^3) reduces the energy requirements for its transportation to the factory (Gonzalez, 1982).

Medium-density biomass briquettes produced from SCCR or bagasse can be used as substitutes for fossil fuels or firewood, thus decreasing deforestation and the emission of greenhouse gases to the atmosphere.

SCCR as an energy source

Studies conducted on industrial scale combustion of bagasse and SCCR have shown a temperature increase in the combustion chamber on ignition of the SCCR (Table 38). Further studies are however required in order to ascertain the effects of alkaline components and the quantity of ash present in the SCCR, since these components are capable of causing blockage of the heat transfer tubes.

Table 38 - Index of the combustion of SCCR and bagasse

Parameters	Sugar Cane Fuels		
	Bagasse	SCCR	Bagasse +SCCR*
Combustion chamber temperature (°C)	981	1 080	1 009
Furnace gases (°C)	879	872	979
Outlet gases (°C)	264	250	277
Excess air (%)	1.99	2.18	1.72
Ashes (%)	2.11	6.05	2.13
Humidity (%)	50.60	25.30	44.00
Steam generated (t/hr)	19.49	18.57	19.31

Sugar cane bagasse

Bagasse serves as a natural fuel of the sugar industry. Bagasse combustion results in the production of thermal energy, which is used for the generation of electricity and to satisfy requirements of the sugar production process. In Cuba for example, 90 to 92 percent of bagasse produced is used for the production of energy, while the remainder is used as a filter aid and for cattle feed.

High fibre sugar cane

Sugar cane of high fibre content is also referred to as *energy cane*. This cane is resistant to pests, diseases, can be grown in soils of medium fertility and has a fibre content which is almost double that of traditional varieties. It has been produced experimentally with agricultural yields of 100 to 180 tonnes per hectare.

Benefits of the use of this cane as an energy source include:

- It produces more than 5 times the quantity of dry matter than do high growth forests;
- It produces more than double the quantity of dry matter than do other cane varieties
- One hectare produces between 15 and 20 tonnes of equivalent fossil fuel;

- Between 100 000 and 200 000 stalks per hectare can be obtained in one crop;
- The use of *energy cane* provides a degree of protection for forests.

Laboratory and factory data for the use of biomass obtained from energy cane as a fuel source is shown in Table 39.

Table 39 - Characteristics of energy cane

A. LABORATORY DATA				
Energy cane	Bagasse % cane	Soluble solid content in the bagasse juice (Brix)	Quantity of sugar in the bagasse (pol % bagasse)	
27.3	53.1	3.75	2.05	
B. FACTORY DATA				
Cane age (month)	Fibre content % cane	Pol content % cane	Extracted juice	
			Soluble solids	Purity
8	17.0	3.0	10.6	48
12	23.8	7.5	15.1	67
24	25.0	-----	9.0	62

Source: Peña and Perez, (1999)

3.3 The generation of electric power and steam for raw sugar production

In the design of sugar processing layouts, the maintenance of a balance between bagasse produced and bagasse burned in furnaces is necessary, in order to produce the steam requirements of the industry. Maintenance of this balance avoids the use of fossil fuels, or the disposal of surplus bagasse as a waste, both of which add overheads to the cost of sugar production.

Steam is used primarily for power generation in the sugar factory as well as for heating purposes. Large energy reserves may be extracted by improving efficiencies in steam generation during sugar cane processing. Cogeneration would allow better conversion of thermal energy into mechanical energy, while improved use of exhaust steam would also result in improved thermal efficiency.

A number of different possibilities might be explored for taking advantage of the energy reserves in sugar cane processing. One proven in practice is the Rankine cycle approach whereby steam generated in the boiler arrives at much higher pressures and temperatures than usual. This steam is passed to prime movers in order to generate the required mechanical energy. Exhaust steam is used in processing, while condensed steam is collected and sent back to the boiler thus closing the cycle. This cycle has proven to be economical in thousands of installations in which it has been tested for reliability. Another possibility is the use of the Combined Cycle, in which two cycles are used for the generation of mechanical energy. Gases are used in the first cycle, while water is used in the second.

Steam generation

A main element of steam generators or boilers, is the furnace in which bagasse is burned in order to generate hot flue gases. These gases pass through heat transfer elements, and water evaporation tube bundles known also as a boiler bank, in which water is converted to steam. Efficiency in steam generation is influenced by heat transfer to water (and steam), and losses in thermal energy on conversion of steam to mechanical energy.

The efficiency of steam generation is expressed on the basis of the percentage of heat liberated in the combustion of bagasse that is transferred to water (steam).

Losses in steam generation occur due to:

- Losses of sensible heat carried by chimney gases;
- Incomplete combustion;
- Conduction and convection through walls;
- Extraction of water.

Losses through chimney gases may vary from 11 percent in well-designed, well-operated boilers, up to 30 percent in incomplete and poorly designed boilers. Incomplete combustion is the consequence of charring of the bagasse resulting in particles of incompletely burned carbon particles, which are dragged by the gases to the chimney. Incomplete combustion of bagasse also results in the production of carbon monoxide instead of carbon dioxide, the final product. Losses by conduction and convection vary between 2 and 12 percent depending on furnace and boiler design, and the condition of the refractory insulation in the plant. Bagasse combustion, furnace design and recovery of sensible heat from the flue gases are critical and worthy of further attention.

Bagasse combustion and furnaces

A main feature of combustion and furnace design is the success in bringing bagasse in contact with air. The bagasse must be fed in a manner that allows its distribution in the total space available. This must be done while maintaining it in contact with the air in the combustion zone. Combustion can be improved by supplying most of the air requirements with primary air. Remaining air is supplied to the total as secondary air, in a higher plane of the furnace in which only ascending gases are present, and bagasse is absent. In order to accommodate elevated standards, new furnaces, namely the horse shoe furnace, the grate furnace and the suspension furnace have been developed. Up to 100 percent of excess air is required in bagasse combustion.

Generation of electric power

Mechanical power can be directly generated by steam prime movers, in the power plant. This power is transported to the machines, which generate the electric power for the factory. Electricity thus generated fulfils the energy demands for illumination, and for the functioning of conveyors, pumps and centrifuges. Prime movers using steam instead of electricity are used in cane preparation, milling, and some pumping operations due to the high-energy requirements of these processes. The use of prime movers avoids double energy

conversion, i.e. mechanical to electrical in the power plant and electrical to mechanical at the site of use.

3.4 The use of steam in raw sugar production

Steam is used in raw sugar production for three main purposes:

- Generation of electricity
- The operation of mechanical equipment or prime movers;
- Manufacturing processes.

Mechanical equipment or prime movers and turbo-alternators require steam at high pressure (10 to 80 kg/cm²) while equipment used in manufacturing requires the use of steam at low pressure (0.7 to 1.8 kg/cm²).

The sugar industry follows various strategies for bagasse utilization in energy production:

- Obtaining maximum bagasse savings without the production of additional electric energy;
- Obtaining maximum electric energy without bagasse savings;
- Generation of electric energy requirements for manufacturing, while obtaining surplus bagasse.

Steam consumption at the sugar factory

High-pressure steam is required at the sugar factory in order to serve as a prime mover for sugar mills and for use in turbo-alternators, for the production of electric energy and reciprocating machines. Low-pressure steam is required for manufacturing processes such as heating of the juice, water evaporation and crystallization of the sucrose or massecuite production. Steam consumption at various stages of the sugar production process is shown in Table 40.

Manufacturing processes use low-pressure steam after mechanical use at high pressure. The system is designed in such a way that 80 to 90 percent of the steam demand in manufacturing is obtained from mechanical equipment, while the remainder is obtained from an expansion valve that reduces the pressure of the steam. A classical thermal schematic diagram of a raw sugar factory is shown in Figure 24.

Table 40 - Steam consumption at different steps of the sugar process

Stages	Steam Consumption		
	(kcal/kg sugar)	% cane	% total
Juice heating and evaporation	1 176	27.3	49.0
Masseccuite boiling	720	16.8	30.0
Prime movers	178	4.2	7.4
Pipe losses	144	3.4	6.0
Condensate losses	48	1.0	2.0
Losses to the atmosphere	24	0.6	1.0
Stoppage losses	72	1.7	3.0
General and vacuum pan cleaning	38	0.9	1.6
Total	2 400	56.0	100.0

Source: Quesada, (1969)

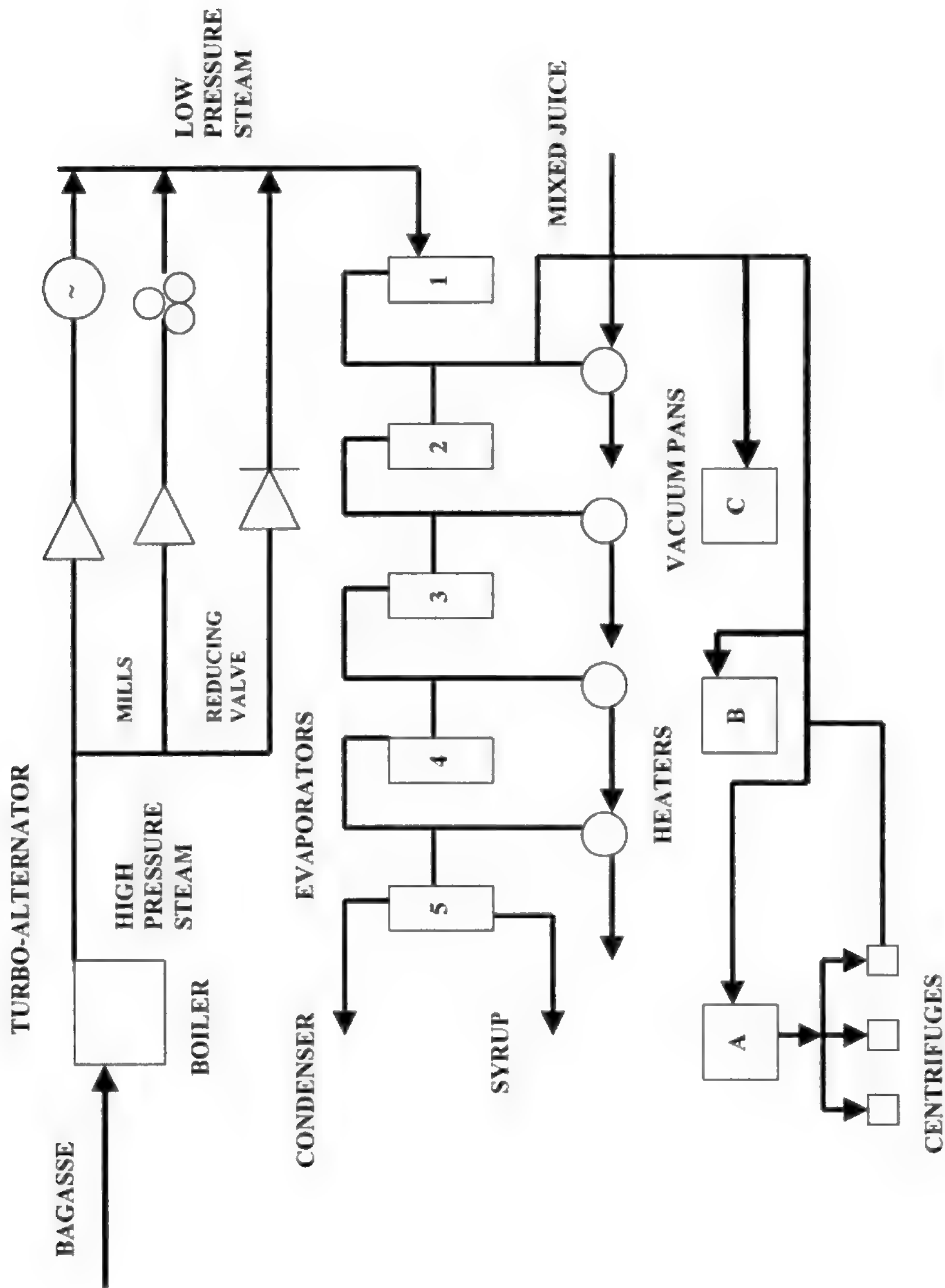


Figure 24 – Thermal scheme for the raw sugar production process

The principal characteristics of steam at each step of the manufacturing process are shown in Table 41.

Table 41 - Equipment and characteristics of the steam at the raw sugar factory

Equipment	Steam Characteristics				Observations
	pd (kg/cm ²)	td (°C)	pe (kg/cm ²)	te (°C)	
A. Prime movers or electric energy generation.					
Electric Energy Generation	10-80	280-450	0,7-1.8	115-135	Counter pressure or condensing turbines are used.
Knives and Shredders	10-28	280-400	0.7-1.8	115-135	Counter pressure turbines are used.
Tandem Mills	10-28	280-400	0.7-1.8	115-135	Counter pressure turbines, electric motors or reciprocating machines are used.
Pumps for boiler water	10-28	280-400	0.7-1.8	115-135	
B. Manufacturing processes					
Heating of juices and molasses	-----	-----	0.0-0.7	100-115	
Evaporation of juices	-----	-----	0.7-1.8	115-135	This must be limited in order to prevent an increase in colour and sucrose inversion
Crystallisation or massecuite boiling	-----	-----	0.0-0.7	100-115	

Where:
 pd, td- pressure and temperature of direct or high pressure steam
 pe, te- pressure and temperature of exhaust steam or low pressure steam

Steam consumption for primary movers and turbo-alternators

Prime movers, sugar mills, boiler feed water pumps, reciprocating machines and the turbo-alternators for electric energy generation obtain their energy requirements from high pressure steam. Steam pressure has a direct influence on the steam consumption of these various pieces of equipment, and on the quantity of electric energy that can be produced. An increase in steam pressure therefore results in decreased requirements for bagasse in the generation of electricity. The cogeneration potential of sugar factories is shown in Table 42 (Gonzalez and De Armas, 1998).

Table 42 - Cogeneration potential of raw or plantation sugar factories

Characteristics of the plant	Quantity of electric energy to co-generate (kWh/tonne cane)
Small steam turbines	0
Steam turbines of 15 MW	40
Steam turbines of 30 MW	75
Steam turbines with an efficient use of process steam	100
Steam turbines with an efficient use of steam with a 60% of bagasse recovery	180
Gas turbine of 50 MW in a factory with an efficient use of steam	240
Gas turbine of 50 MW in a factory with an efficient use of steam and 60% of bagasse recovery	350

Source: Navia, *et al.*, (1990)

Steam consumption for the manufacturing process

The economic use of steam in the manufacturing process can have a significant impact on steam consumption for the production of raw or plantation white sugar and can consequently allow the use of bagasse in the following applications:

- As a substitute for fuel oil
- As a fuel to increase the generation of electricity
- As a raw material for the production of paper, particle boards furfural, animal food, etc.

Steam is consumed at various steps of the raw sugar production process:

1. Extraction step

In diffusion extraction technology, steam is applied for:

- Heating the macerated juices
- Heating the circulation juice
- Heating the diffusion juice
- Heating the press waters

In the case of tandem mills, where it is not usual to heat the maceration juices, there are two operational systems: the application of cold imbibition water or the application of hot imbibition water. Condensates rather than steam are normally used for this purpose.

2. Purification step

At the purification step, steam is used for:

- Heating the mixed juice obtained subsequent to extraction.
- Heating the clarified juice to the temperature of the first evaporator vessel.

3. Evaporation step

At the evaporation step, steam is used for:

- Evaporating the water from the juice, in order to increase the soluble solid content

4. Massecuite boiling

In massecuite boiling, steam is used for:

- Increasing the soluble solid content of the massecuite
- Increasing the temperature of the intermediate molasses
- Heating the syrup at the purification step

Low pressure steam obtained from either turbo-alternators, steam turbines, reciprocation machines of the mill, tandem reciprocation machines for vacuum pumps or steam pressure reducing valves, is used in all of these manufacturing applications.

CHAPTER 4

PROTECTION OF THE ENVIRONMENT

Introduction

Any creation or modification to technology must consider protection of the environment along with production efficiency and cost effectiveness.

Sugar production does not end at the sugar warehouse or at the marine terminal. It can only end when residues and residual matter produced in the process are adequately disposed of. Residuals in the production of raw sugar from sugar cane are not harmful to the environment when properly used. In fact, many residuals do not need to be treated prior to re-use and in certain cases, offer prospects for financial returns.

Raw sugar production can be considered a 'clean manufacturing' process if residues and residuals generated in the process are appropriately managed, and if agricultural practices and technologies applied in the process avoid or minimize environmental impact. Residual contamination can be reduced either by recycling residuals produced during processing, or by using technologies which lower resultant contamination levels.

Residuals generated by sugar-cane production and in sugar processing can have either a direct or indirect environmental impact. SCCR, bagasse, combustion gases, filter cake, fly ash, and furnace ash can have a direct environmental impact if not properly disposed of or utilized. Soil erosion and fossil fuel consumption for diverse agronomic practices during sugar production on the other hand, have an indirect environmental impact. Biological contamination from organic materials and non-biological contamination in the form of oil spills, solids in suspension, acid and caustic solutions are possible.

Sugar cane residuals can either contribute to increasing the economic value-added to sugar production or can have a negative impact if not adequately treated (Veiga, 1993).

4.1 Residuals from raw cane sugar production

Sugar can be produced from clean sugar cane with the minimum use of chemical products through the application of technologies that have a positive ecological and economic impact.

Residues produced at the agricultural stage during sugar production

Agricultural practices such as the application of chemical products for weed and pest control, the application of fertilizers and irrigation, can have a negative environmental impact during the cultivation of sugar cane. Organic technologies however, offer possibilities for reducing or avoiding this negative environmental impact. Table 43 lists several organic technologies, which have favourable ecological results.

Table 43 - Technologies applied in the organic cultivation of sugar cane

Technologies	Ecological Objective
Sowing in contour	Reduced soil erosion.
Straw coverage	Preserve dampness and decrease weed formation.
Crop rotation	Soil protection incorporating nutrient substances.
Application of wastewater for irrigation	Partially substitute chemical fertilization requirements and disposal of industrial wastewater.
Application of compost	Add organic matter to soil.
Application of filter cake	Add organic matter, minerals and salts to the soil.
Use of bagasse combustion ashes	Application of minerals and salts to the soil.
Development and application of bio-fertilizers: <i>Azotobacter</i> , <i>Azospirillum</i> <i>Rizobium</i>	Partial substitution of chemical fertilizers.
Use of the lipsophaga fly	Biological control of pests
Gravity Irrigation	Reduced requirements for the use of fossil fuels.
Development of cane varieties	Biological control of pests and diseases.

Residues produced at harvest

Crop burning and the production of crop residues such as SCCR have an adverse ecological impact. A portion of crop residues produced remains in the field, while the remainder which constitutes the EM, enters the factory with the cane. These residues are applicable as animal food, as substitutes for fossil fuel or as herbicides (Table 44). Some of these residues may also be incinerated, thus emitting carbon dioxide into the atmosphere (Figure 25).

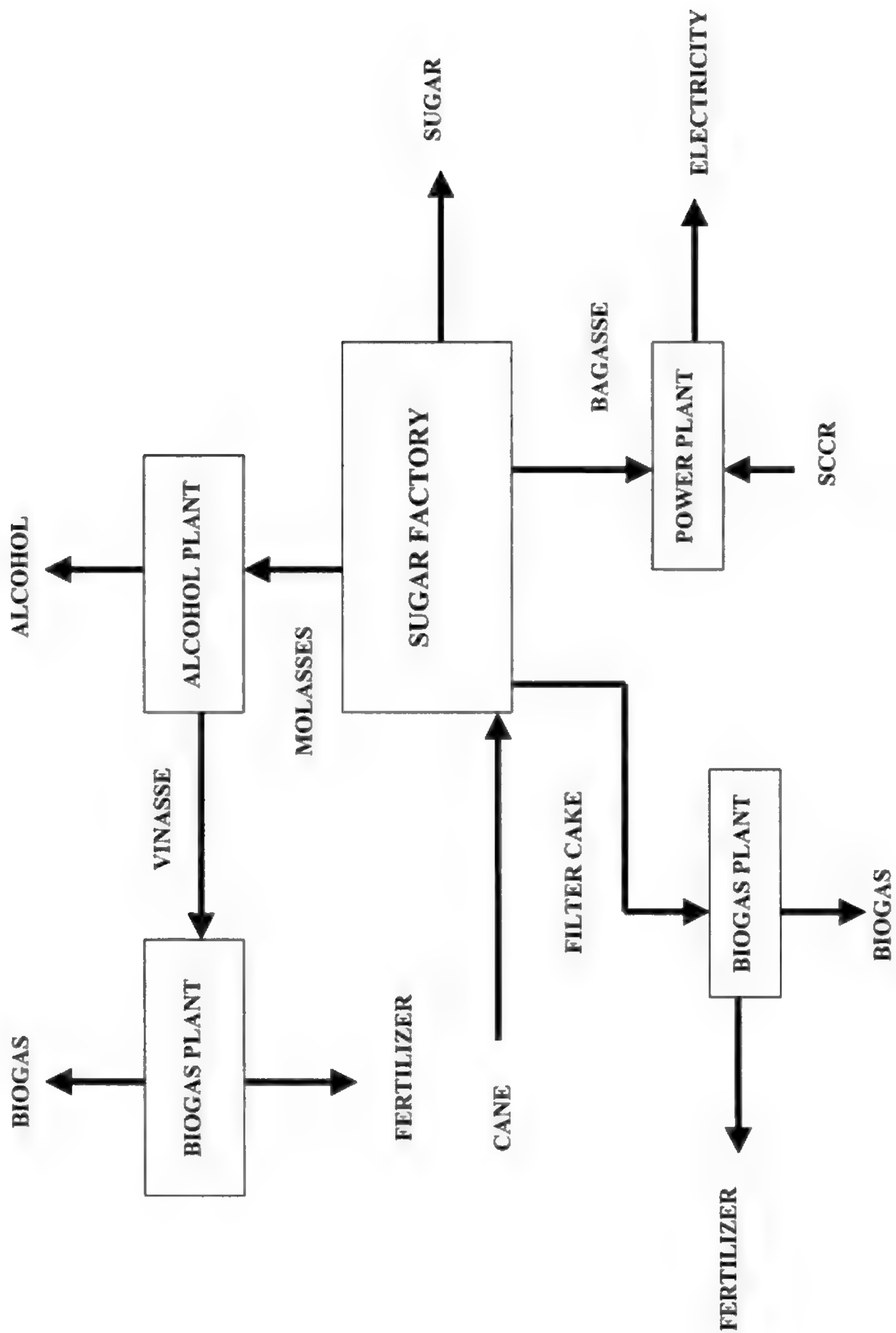


Figure 25 – Residues from raw sugar production and their uses

Maximal sugar recovery is obtainable when clean cane is used as the raw material in the production of raw sugar. As discussed in Chapter 1, burning is one method used in the production of clean cane. Burning can however have both a direct and an indirect environmental impact:

- Emission of carbon dioxide to the atmosphere;
- Increased requirements for the use of herbicides due to a reduction in straw coverage at the field level;
- Loss of soil nutrients and linkages to soil microorganisms;
- Decreased soil nitrogen levels;
- Reduced soil porosity and obstruction of water infiltration;
- Elimination of natural defences against pests.

Table 44 - Alternative uses of SCCR and its effect on the environment

Form	Use	Effect on Environment
Cut	Steam generation for: - Manufacturing - Electricity production	Substitution for fuel-oil
Densified	Cooking	Substitution for firewood, charcoal, gas oil or kerosene
Cut or natural	Animal food	Substitution for other animal feed
Natural	Soil coverage	Partial substitution for herbicides; maintenance of soil humidity

Residues produced at the industrial stage during sugar production

A number of potentially harmful residuals in the solid, liquid and gaseous form are produced at the industrial stage of sugar processing.

Solid residues

Solid residues include bagasse, combustion ash, fly ash and filter cake. Bagasse combustion results in the production of ash having a composition similar to that of soil entering the factory with the cane. The ash content of bagasse varies between 1 and 4 percent with an average of about 2 percent, while that of SCCR is approximately 8 percent.

Fly ash is a harmful residue that becomes dispersed into the environment and eventually precipitates. Approximately 5 to 6 tonnes of fly ash are produced per tonne of sugar cane. Fly ash may be mechanically separated or collected with the use of cyclones, by water scrubbing or by electrostatic capture. Mechanical collection results in poor recovery of fly ash. It is therefore combined with either water scrubbing or electrostatic capture. Water scrubbing is effective and less costly than the electrostatic process, but water consumed by the process must undergo treatment for recycling. In water scrubbing, the fly ash is separated from the flue gases by a water curtain. Ash is recovered from the water with the use of parabolic screens. Potential however exists for the use of fly ash as a filter aid in rotary vacuum filters.

Filter cake (cachaza or press mud) is obtained at the clarification step during sugar manufacture (Chapter 1). On the basis of its high biological load (BOD ranging between 38.57 and 71.59), filter cake should not be sent to water reservoirs, rivers, lakes, oceans or other sensitive ecosystems. Characteristics of filter cake are shown in Table 45.

Table 45 - Characteristics of filter cake (% dry basis)

Country	Organic Matter	Nitrogen	P ₂ O ₅	K ₂ O
Argentina	73.31	2.34	6.34	-----
Brazil	85.14	1.41	1.04	0.72
Cuba	-----	1.60	1.38	0.50
South Africa	-----	1.93	2.34	0.36
Mauritius	87.32	2.05	1.95	-----
Jamaica	-----	1.41	2.81	0.35
Puerto Rico	-----	2.19	2.77	0.44
Philippines	83.77	1.12	3.63	0.53
Argentina*	65.21	0.95	3.27	0.75

*Represents the mean of 14 sugar factories of Tucuman province.

Source: Cardenas and Guzman, (1983)

Filter cake can be used in a number of applications. It is applicable in the production of organic and mineral fertilizers and in the production of animal feed biogas, fertilizer, compost and wax.

Organic and mineral fertilizers from solid industrial residues

Filter cake, which contains nitrogen, phosphorus, potassium and organic matter, can be transported from the factory for direct use in the field, as a substitute for inorganic fertilizers. The low density of these fertilizers, however, implicates relatively high transportation costs.

The use of filter cake as a fertilizer is beneficial to the environment in a number of respects:

- Soil characteristics are improved due to increased organic matter;
- Soil permeability is increased;
- Agricultural cane yield is increased;
- Inorganic fertilizer can be replaced.

Table 46 compares filter cake fertilizer with inorganic fertilizers.

Table 46 - Influence of the treatment of filter cake on the sugar cane yield in yellowish-red ferralitic soil

Fertilizer Type	Fertilization Procedure	Plant cane yield (tonnes/ha)	First ratoon yield (tonnes/ha)	Second ratoon yield (tonnes/ha)	Accumulated for three campaigns yield (tonnes/ha)
INORGANIC	N - P- K 113-36-107	135.11	138.50	67.69	341.30
ORGANIC	Filter cake 30 tonnes/ha	167.69	136.45	47.33	351.47

The direct application of filter cake as a fertilizer is recommended for:

- Preparation of the soil for planting;
- Application at the bottom of the furrow prior to seeding;
- Distribution through irrigation channels.

The fertilizer can be applied to the field at a level of 75 tonnes/ha by homogeneous distribution. Filter cake can either be directly transferred from the filters to the agricultural soil or can be diluted with water prior to being transferred to the fields.

Compost from solid industrial residues

Compost is produced by the degradation of organic matter through either natural or controlled biotechnological processes. Filter cake, SCCR, bagasse, distillery residuals, animal manure and other organic materials are all substrates for compost production. Compost is applicable in recovering soil fertility. It facilitates the fixation of nitrogen from the air, water retention, return of soil nutrients and increases the action of inorganic fertilizers. A flow chart of compost production from various by-product streams is shown in Figure 26 .

The mean composition of various materials used in compost manufacture is shown in Table 47.

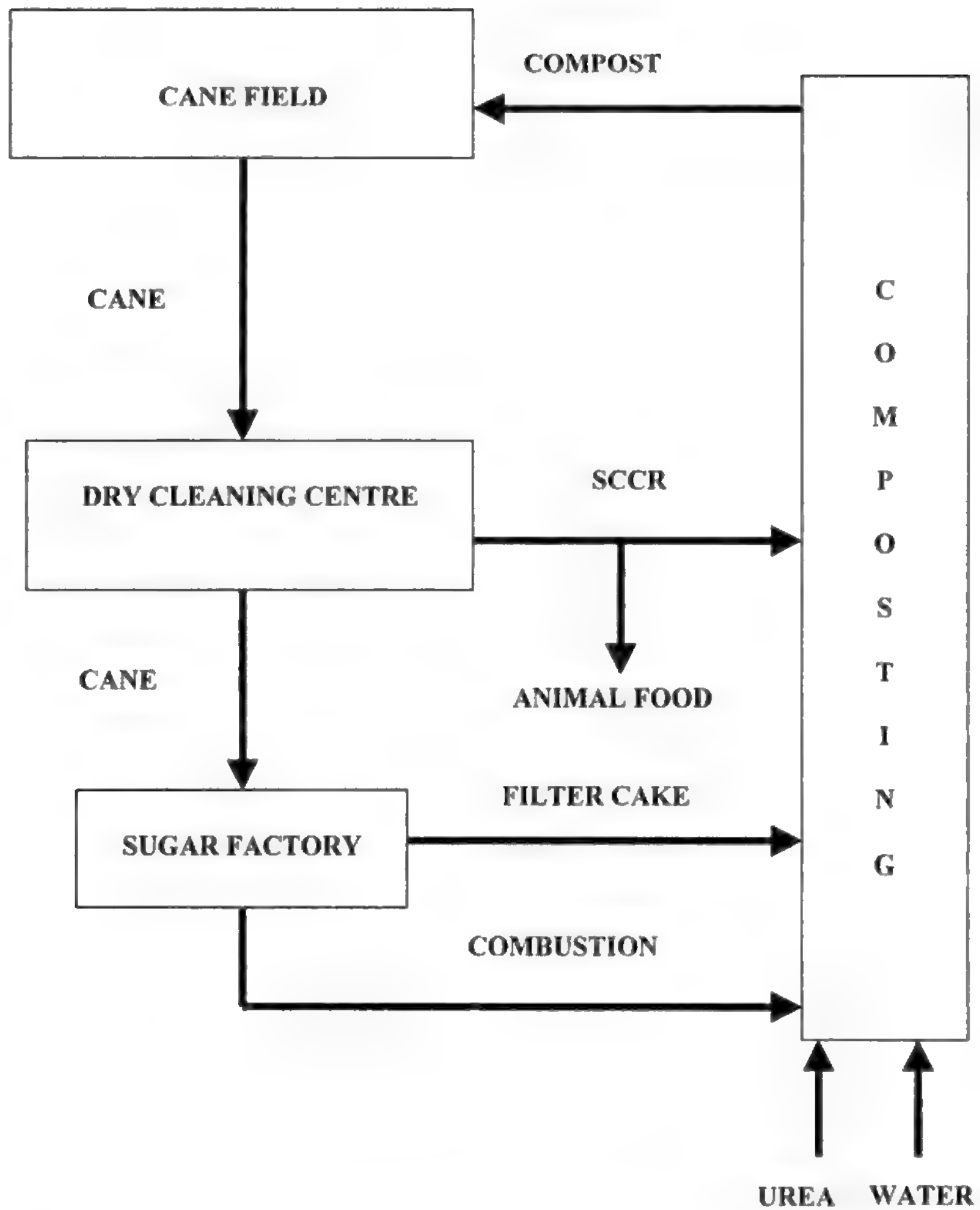


Figure 26 - Flowchart for the production of compost from residues of raw sugar production (Anon, 1991)

Table 47 - Mean composition of raw materials used in compost production

Material	Humidity %	Mean quantity in % dry base					Relation C/N
		Organic material	C	N	P ₂ O ₅	K ₂ O	
Cachaza	80.0	80	44.4	1.5	1.8	0.30	29.6
Bagasse	50.0	90	50.0	0.39	1.02	0.87	128.2
Distillery vinasse	94.5	76	42.2	12.7	2.70	36.5	3.3
Cattle dung	70.0	82	45.5	1.9	1.5	2.0	23.9
SCCR	40.0	94	52.2	0.35	0.20	1.25	149.1
Yeast must	90.2	74	41.0	0.15	0.12	---	273.3

Animal feed from solid industrial residuals

Filter cake is used in the production of animal feed. One such product known as GICABU, combines filter cake with distillery residuals or slops. It can replace 15 percent of the dry matter content in all the diets of dairy cattle and between 45 and 60 percent in maintenance feeds for cattle.

GARANVER is another such product which is produced by mixing acid and alkaline effluents obtained after chemical cleaning of the heating surface of evaporators and heaters, with filter cake, residual waters, pith (small particles of bagasse) and urea. Filter cake accounts for 70 percent of the composition of this feed.

Biogas and fertilizer from solid industrial residues

Decomposition of organic matter under anaerobic conditions results in the production of a gaseous fuel known as biogas. Biogas constitutes a mixture of gases, which include methane (70 percent), carbon dioxide and hydrogen sulphide. The caloric value of biogas ranges between 4 700 and 5 500 kcal/m³.

Biogas can be produced from a mixture of residual water (pH 6.8 to 7.2) and filter cake. One cubic meter of biogas can be produced for every tonne of cane milled. The resultant mud remaining subsequent to biogas digestion is used as fertilizer.

Steps in the production of biogas from industrial effluents are summarized in Figure 27. They include:

- Degreasing of the wastewater;
- Removal of suspended solids;
- Mixing of the materials;
- Fermentation in an anaerobic digester;

- Storage at low pressure;
- Purification;
- Compression;
- Storage at low, medium and/or high-pressure.

Critical conditions for biogas production include:

- Anaerobic conditions;
- Neutral pH conditions (7.0-7.2);
- Temperatures ranging between 35 and 37°C;
- Carbon to nitrogen ratios varying between 25:1 and 30:1;
- Solids content varying between 9 and 10 percent;
- Avoidance of harmful elements that can affect survival of the methane producing bacteria.

Biogas production can considerably improve the quality of life of populations in small villages, and can have a positive environmental impact. Biogas is also applicable in the cogeneration of electric energy and/or the substitution of fossil fuel in industrial facilities.

Benefits derived from the production of biogas include:

- Substitution of fossil fuel with biogas, thereby decreasing the emission of greenhouse gases;
- Improved quality of life due to increased availability of time for other activities such as education;
- Improved health of women and children due to the elimination of the hazards of inhaling firewood smoke;
- Reduced deforestation;
- Reduced soil erosion;
- Production of an organic fertilizer in conjunction with the biogas;
- Protection of water reservoirs;
- Water emerging from the biogas plant is used for irrigation.

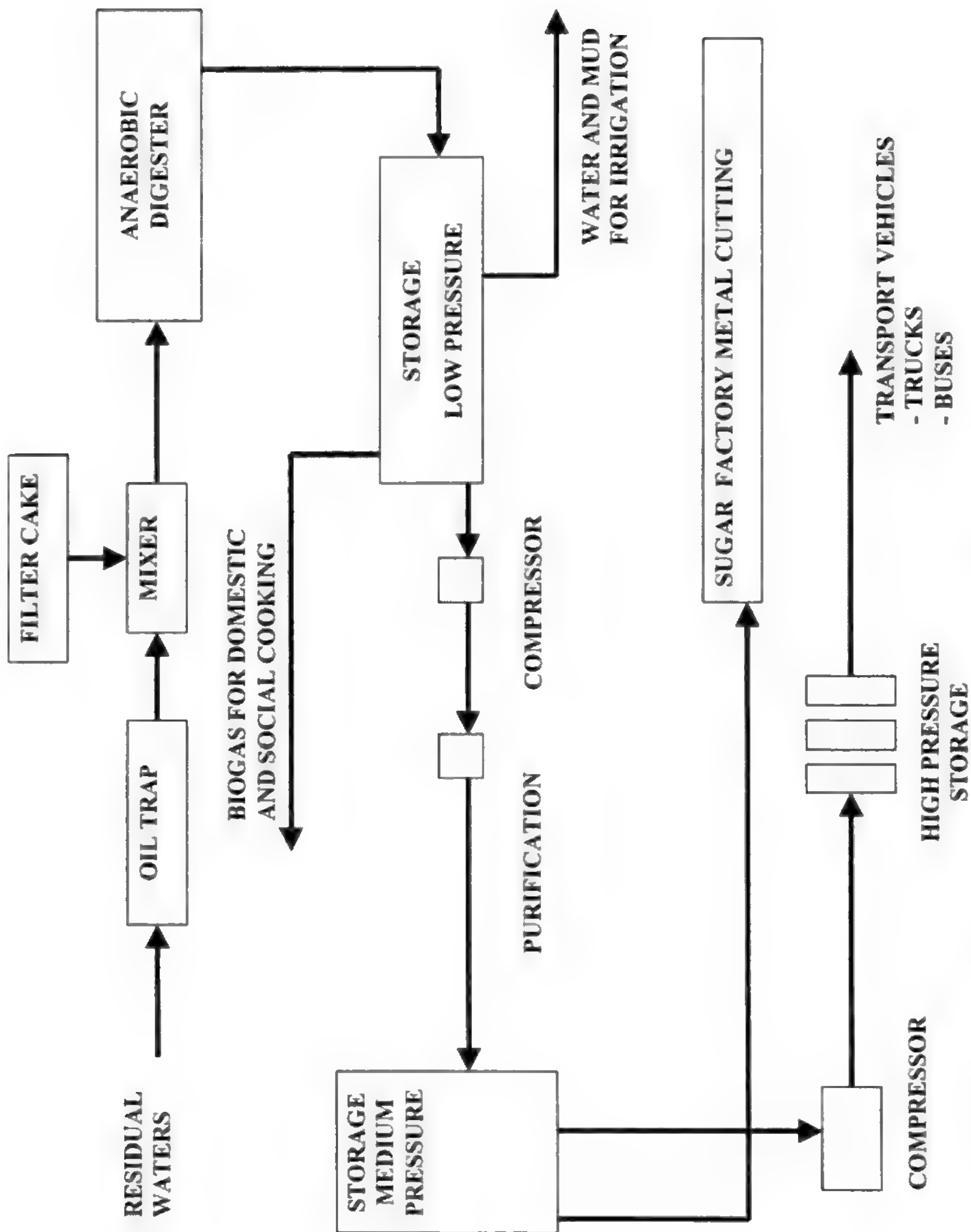


Figure 27 – Flowchart for the production and use of biogas from filter cake

Low-pressure biogas is used in cooking and lighting, for internal combustion engines and for power generation

Wax from solid industrial residuals

Studies have been conducted on the production of wax from solid industrial sugar processing residues, for use in pharmaceutical applications.

Liquid residuals

Liquid residuals originate from water consumption in the factory and water in the sugar cane. Liquid residuals generally contain organic, mineral and biological materials. Thus in addition to considering factors such as BOD and COD, solids content, pH and temperature, the contamination load in liquid residuals must be determined (Flores, *et al.*, 1984).

Water consumption

Water is consumed by the sugar factory both for manufacturing processes and for cooling (Vales, 1986):

a. Manufacturing requirements:

- Washing the cane;
- Imbibition at the juice extraction stage;
- Filter cake washing;
- Preparation of milk of lime;
- Sugar centrifugation;
- Dilution of intermediate molasses.

b. Equipment requirements and repositioning at different circuits:

- Cooling of the bearings.
- Water cooling in spray ponds or cooling towers.

A material balance of water requirements during the manufacture of raw sugar is shown in Table 48 (Rodriguez, 1978).

Table 48 - Water balance in raw sugar production

Origin or destination	Quantity of water for different evaporation systems (%)		
	Triple effect	Quadruple effect	Quintuple effect
Cane	100.00	100.00	100.00
Bagasse	21.40	21.40	21.40
Final molasses	1.00	1.00	1.00
Raw Sugar	0.08	0.08	0.08
Filter cake	3.70	3.70	3.70
Steam circuit losses	6.40	6.40	6.40
Hot water surplus in evaporation	8.00	17.30	23.10
Condensers for vacuum pans plus	59.40	50.00	44.20

Water consumption during raw sugar production is summarized in Table 49.

Table 49 - Water consumption in a raw sugar factory

Use	Parameters				
	Quantity (m ³ /tc)	BOD (mg/l)	pH	Temperature (°C)	Volatile solids (mg/l)
Condensers *	17-20	46	6.6-7.5	41	420-530
Cleaning of heat transfer surfaces of equipment	0.8-1.2	460-740	6.6-7.5	32-44	170-290
Cleaning of filters	0.1-0.3	7 300-12 000	3.8-4.7	38-42	5 600-56 600
Overflow and leakage in water cooling systems of technological equipment	0.3-0.8	300-900	6.1-7.0	40-44	170-290
Filter cake dilution **	0.1-0.2	3 700-4 600	6.1-6.8	27-44	16 500-22 200

* Water consumption in those factories that do not have a system for cooling and recirculation water.

** Water present when the filter cake is diluted; in dry manipulation of the filter cake water is not present.

Source: Baguant and Ramjuawon, (1996)

Other applications in which water is used include:

- Cane washing;
- Overflow of tanks and equipment;
- Floor washing;
- Boiler extractions;
- Workshops factory and transport (basically oil and grease);
- Lavatories;
- Quality control laboratories.

Residues and residuals which contain water

The water balance of sugar factory water is associated with a number of residuals. These include:

- Sugar cane bagasse;
- Final molasses;
- Filter cake;
- Raw sugar;
- Spray ponds, cooling towers, close circuits, etc.

Properties of wastewater

Wastewater resulting from raw sugar production is unsuitable for direct discharge into aquatic eco-systems such as rivers, ponds, dams and the sea, owing to its high organic content, which necessitates oxygen consumption. If allowed to enter into aquatic eco-systems, this wastewater absorbs oxygen and has a net negative impact on aquatic organisms.

The main contaminants of wastewater include:

- Oil and grease;
- Micro-organisms;
- Suspended solids;
- Organic materials;
- Inorganic materials.

These contaminants are produced from cooling systems and from sanitary and hygienic cleaning during manufacturing processes. Classification of wastewater on the basis of its BOD is shown in Table 50, while characteristics of wastewater produced during sugar processing are shown in Table 51.

Table 50 - Classification of wastewater on the basis of its BOD

Classification	BOD ₅ (mg/l)
Weak	50-300
Strong	300-2 000
Very strong	more than 2 000

Source: Valdes, E., (1979)

Table 51 - Characteristics of wastewater emitted from sugar factories

WASTEWATER	Wastewater flow (l/s) (%)		DBO ₅ (mg/l)	Oil and grease (mg/l)	Sediment-solids (mg/l)	pH and temperature (°C)
Cane wash	230-350	27	700-1 500	-----	200-400	-----
Cooling of mills	15-30	2	-----	40-150	-----	-----
Diluted filter cake	10-20	2	1 500-12 000	-----	300-350	-----
Condensers	500-900	66	60-200	-----	-----	38-54
Chemical cleanings	5-10	0.8	750-1 200	-----	-----	4-8
Floor washing	5-10	0.8	200-400	15-30	-----	-----
Domestic*	2.5-10	0.6	200-400	-----	50-150	-----

Source: Zedillo, (1993)

Wastewater treatment

The disposal of the residual water from the sugar factory in lakes or ponds near the factory results in the generation of foul odours. Wastewater generally requires treatment in order to be rendered usable and safe for the environment. Wastewater disposal must be strictly controlled.

Wastewater can be treated by the following steps:

- Preliminary separation of high volume materials
- Primary separation of sedimented substances;
- Secondary separation for removal of organic materials
- Tertiary separation in order to remove any remaining organic materials

Uses of wastewater

Wastewater is highly recommended for use in irrigation. It must however undergo either aerobic or anaerobic treatment prior to being used for that purpose. Wastewater obtained subsequent to anaerobic digestion during biogas production, for example, can be directly used for irrigation purposes.

Direct use of wastewater discharged from the sugar factory for irrigation purposes, necessitates retention of the water in a lagoon system consisting of two lagoons, for one to

two days. In the first lagoon, the wastewater is cooled and homogenized. It is then moved to the second lagoon, which serves as a reservoir for irrigation. This second reservoir has the ability to assimilate residuals emitted from the wastewater.

In order to be used in irrigation applications, wastewater must satisfy a number of criteria. These are summarized in Table 52.

Table 52 - Specifications of wastewater for irrigation applications

Criteria	Electric conductivity (CE) Mmhos/cm	Total soluble salts (SST) ppm	Sodium absorption relation (RAS)	pH
Good	<1.50	<960	<4	6-7
Regular	1.5-1.8	960-1 150	4-7	5.0-6.0 7.0-7.8
Bad	1.8-2.4	1 150-1 530	7-10	4.0-5.0 7.8-8.4
Non-usable	>2.4	>1 550	>10	< 4 or >8.4

Source: Irrigation and Drainage for Sugar Cane, (1995)

The following must be taken into consideration for the application of wastewater in irrigation (Paneque, *et al.*, 1998)

- Wastewater for irrigation purposes must be consistent with soil and plant requirements;
- Wastewater of high salt and sodium content and acid waters, should not be applied in irrigation;
- Residuals must be cooled and homogenized prior to their application to the soil;
- Light soil areas irrigated with wastewater must be irrigated in alternate years on an annual basis, while heavy soils irrigated with wastewater must be alternately irrigated on a biannual basis;
- Soils irrigated with wastewater must be periodically analysed.

Alternatives for water saving

During the sugar manufacturing process, water used by equipment serves the purpose of cooling bearings, cooling systems and for water circuit repositioning. In some cases cooling water is discharged subsequent to use. Installing closed circuits in which the initial water temperature is restored by cooling in spray ponds or in cooling towers can result in reducing water consumption. Table 53 shows an example of the water saving that can be achieved for a sugar factory having a cane milling capacity of 1 000 tonnes per day.

Table 53 - Examples of water saving that can be accomplished in sugar processing *

Equipment or Operation	C A S E S (m ³ /h)					
	A	B	C	D	E	F
Vacuum pumps	4.4	4.4	4.4	4.4	0.16	4.4
Turbo-alternators	7.4	0.26	7.4	7.4	0.26	7.4
Crystallizers	98.6	8.6	8.6	0.31	0.31	8.6
Mill tandem	22.6	22.6	0.8	22.6	0.80	22.6
Water seals	11.6	11.6	11.6	11.6	0.41	11.6
Reposition to condensers	15.8	15.8	15.8	15.8	15.8	741.6
Total	70.4	63.3	48.6	62.1	17.7	796.2
m ³ /t cane	1.67	1.52	1.16	1.49	0.42	19.1

* Represents mean values

Source: Rodriquez, (1978)

CASES:

- A. With water recirculation only of the barometric condensers.
- B. With water recirculation of barometric condensers and closed circuit for turbo-alternator.
- C. With water recirculation of barometric condensers and closed circuit for water used at the mills of the tandem.
- D. With water recirculation of barometric condensers and closed circuit for crystallizers.
- E. With water recirculation of barometric condensers and closed circuit for all cooling operations.
- F. Without any recirculation circuit including the barometric condenser water.

The following can decrease wastewater contamination and flow:

- Use of a closed circuit with a small cooling tower for water applied in the cooling of the brass bearings of mill rollers, mill turbine bearings, turbo-alternator bearings, and in the cooling of final molasses;
- Installation of a spray pond or cooling tower for decreasing the temperature of the barometric condenser water in cases where the water is not recycled;
- Elaboration of a scheme, which optimizes use of condensates obtained at various stages of the manufacturing process. These include:
 - Boiler feed water
 - First heating of the mixed juice
 - Imbibition of the bagasse blanket in mills or diffusers
 - Heating the final massecuite in the low grade crystallizer
 - Dilution of intermediate molasses: A and B
 - Sugar centrifugation

- Use of minimum amounts of water for washing equipment and auxiliaries such as: juice, syrup and molasses tanks, evaporator vessels, clarifiers, vacuum pans, mills, etc;
- Avoidance of leakage and tank spills, pumps, pipes, etc;
- Segregation of water streams on the basis of their composition, organic load, etc.

Wastewater effluents must be separated both on the basis of organic load and their chemical constituents. Thus acid and alkaline streams emitted from the chemical cleaning of the evaporators must be discharged in separate streams. Acid streams must be separated in special tanks and may be incorporated into the wastewater stream for irrigation in a controlled fashion. Alkaline wastewater streams are applicable in the preparation of animal food by mixing with pith (small particles of bagasse), final molasses, urea and water (Sour, 1990, Penichet, *et al.*, 1982).

Standards for water emission to different eco-systems

The main residual gas discharged into the atmosphere during sugar manufacture is CO₂ generated by the combustion of bagasse. Combustion of cane biomass (SCCR + bagasse) results in the discharge of approximately 36 tonnes of carbon dioxide. The production of carbon dioxide from cane biomass does not, however, have an environmental impact due to the balance achieved with the quantity of CO₂ absorbed by cane during its vegetative cycle. Biomass combustion does not release sulphur compounds into the environment and is consequently, not a cause of acid rain (Cuban Standards, 1999).

4.2 Residuals from sugar related processes

Alcohol and paper are the main by-products of sugar cane processing.

Residuals from alcohol production

Alcohol is directly produced from either cane juice or final molasses. Distillation slops is an undesirable by-product of alcohol distillation and a major concern in most sugar cane producing countries, since 10 to 15 litres are generated for every litre of alcohol produced.

Effluents from alcohol production may be utilized in:

- Soil irrigation and fertilization;
- Torula yeast production;
- Biogas production;
- As boiler fuel in a concentrated form.

CHAPTER 5

COMMERCIALIZATION OF SUGAR

Introduction

Sugar is produced from both sugar cane and sugar beet. Sugar cane is harvested in both tropical and sub-tropical countries, many of which are developing countries. Sugar is used in a number of food applications, but is also the cause of a number of medical conditions such as obesity, dental cavities, arteriosclerosis and diabetes.

Currently, sugar fetches a low price on world markets, which does not provide an economic stimulus for either the expansion and/or the modernization of sugar production. This situation might however be improved if sugar processing is integrated with by-product processing.

Developments in the sugar production process should incorporate processes that promote clean production, protect human health, avoid damage to the environment and offer economic advantages. Sustainable development of sugar production should satisfy the necessities of the current generation without compromising future generations (Bernardin, 1978).

5.1 Sugar production

Sugar is produced from sugar cane in 67 countries, and from the sugar beet in 39 producer countries. Beet sugar is produced in temperate climates while cane sugar is produced in tropical and subtropical climates. Globally, sugar is produced by 2 520 factories. Cane sugar accounts for approximately 65 percent of world sugar production while sugar beet accounts for 35 percent. Table 54 shows world sugar production in various geographic regions. Although according to data in this Table, world sugar production showed a relatively minimal increase, between 1970 and 1997, the world sugar market is by no means saturated.

Table 54 - World sugar production in various geographical regions for the period 1970-1997 (thousand tonnes)

Region	Years					
	1970	1980	1990	1995	1996	1997
Africa	4 731	5 965	8 094	7 367	8 213	8 627
North/Central America	19 427	18 554	20 448	18 141	19 486	20 180
South America	8 523	13 372	13 363	19 960	21 041	22 023
Asia	14 151	16 356	32 286	40 512	43 432	39 561
Europe	23 710	27 373	32 432	26 787	28 290	27 189
Oceania	2 518	3 811	4 094	5 533	6 153	6 363
World	73 060	85 431	109 717	118 300	126 615	123 947

Source: FAO Production Year Book, Vol. 51, 1997

5.2 Sugar consumption

Sugar may be consumed either directly or indirectly. Indirect sugar consumption accounts for as much as 60 percent of sugar consumed in developed countries. Table 55 summarizes sugar consumption between 1970 and 1997 in various geographical regions.

Table 55 - World sugar consumption in various geographical regions for the period 1970-1997 (thousand tonnes)

Region	Years					
	1970	1980	1990	1995	1996	1997
Africa	4 136	6 867	8 753	9 60	9 877	10 659
North/Central America	14 979	15 371	15 967	16 756	16 921	17 082
South America	6 610	10 703	11 515	13 762	14 265	14 848
Asia	16 257	21 160	35 778	44 165	45 943	46 757
Europe	29 182	32 729	34 464	29 254	30 001	29 952
Oceania	950	1 018	1 125	1 204	1 271	1 328
World *	72 115	87 850	108 743	116 802	120 092	124 544

* A note of the reference indicates that there are adjustments for unknown net-trade.

Source: FAO Production Year Book, 1997, 1980 and 1990.

The slow rate of growth in world sugar consumption has been influenced by increased production of high fructose corn syrup and increased domestic sugar prices. Poorest regions of the world in fact show a deficit in sugar consumption (Table 56).

**Table 56 - Sugar consumption by population in various regions for the period 1992 to 1996
(kg/inhabitant/year)**

Year	Europe	North * America	Central** America	South America	Africa	Asia	Oceania	World
1992	39.3	32.1	50.9	42.4	13.9	12.0	42.2	20.4
1993	37.5	32.6	48.0	42.3	13.9	12.4	41.6	20.6
1994	36.6	32.5	46.1	42.0	13.5	12.7	44.1	20.2
1995	37.0	33.2	44.3	42.9	13.6	12.9	43.4	20.1
1996	36.2	33.4	43.8	43.9	13.3	13.0	43.7	20.4

* Canada and United States of America

** Includes the Caribbean countries.

Source: International Sugar Organization, Sugar Year Book, 1970, 1980 and 1990.

Low sugar consumption in a number of developing countries is primarily due to the lack of economic resources for both the production and consumption of sugar. Sugar consumption in a number of these countries is shown in Table 57.

5.3 Cane sugar production costs

Currently, the cost of producing sugar exceeds that of world market prices for sugar, due to the use of outdated sugar manufacturing equipment of low efficiency in a number of sugar producing countries. Current world market prices for sugar production vary between US\$10 and US\$12 per pound. However mean production costs for white sugar production vary from US\$22 per pound in the European Union to US\$35 per pound in Italy. The cost of sugar production is much more favourable in France, where the mean production cost is US\$0.18 per pound. This situation has impeded the expansion and development of sugar processing and caused the closure of several sugar manufacturing concerns in developing countries. A few countries such as Australia and Thailand have however been able to modernize their sugar industries and improve their production efficiencies over the past few years.

The commercialization of white sugar has increased owing to its good economic potential. New installations are currently being built for the refining of raw sugars. Production costs for refined raw cane sugar are lower than for those for refined raw beet sugar. Additionally, the cost of directly producing white sugar is lower than the cost of producing refined white sugar from raw sugar. The major trend for the future of white sugar commercialization is to increase the quality of plantation white sugars while decreasing their quantity and transportation costs (Cerro, 1994).

Table 57 - Countries with low sugar consumption

No.	Country	Population (million inhabitants)	Sugar consumption (kg/inhabitant/year)
1	Afghanistan	20.89	2.2
2	Bangladesh	120.07	2.4
3	China	1 232.08	6.3
4	Kampuchea	10.27	5.3
5	Myanmar	45.92	1.1
6	Nepal	22.02	0.7
7	Vietnam	75.18	8.1
8	Burkina Faso	10.78	4.1
9	Burundi	6.22	1.8
10	Central. African Rep.	3.34	1.4
11	Chad	6.52	8.5
12	Comoros	.63	2.9
13	Ethiopia	58.23	3.3
14	Gabon	1.11	6.1
15	Ghana	17.83	7.0
16	Guinea Bissau	1.09	5.8
17	Liberia	2.25	2.1
18	Madagascar	15.35	6.4
19	Mali	11.13	5.2
20	Mozambique	17.79	2.6
21	Niger	9.45	2.3
22	Nigeria	115.02	5.5
23	Rwanda	5.39	0.5
24	Sierra Leona	4.29	3.0
25	Tanzania	30.80	5.0
26	Uganda	20.26	6.6
27	Zambia	8.28	7.6
28	Zaire	46.81	1.9
29	Papua N. Guinea	4.40	8.8
30	Western Samoa	0.17	9.6
Total		1 923.60	4.5
World		5 767.78	21.0

5.4 Sugar prices

The 1970s saw tremendous changes in world sugar prices. During the first half of that decade, world sugar prices increased by a factor of 67, while at the latter part of that decade, sugar prices declined owing to increased sugar production and the introduction of High Fructose Corn Syrup (HFCS) on world markets.

As previously discussed, sugar prices are currently inadequate to cover the cost of sugar production in many countries. Price variations on world sugar markets are given in Table 58.

Table 58 - Mean annual variation of the world sugar prices

Year	Price (US \$/tonnes)	Year	Price (US \$/tonnes)	Year	Price (US\$ /tonnes)
1900	64	1950	110	1985	90
1910	63	1960	69	1990	277
1920	250	1970	83	1995	293
1930	25	1975	452	1996	264
1940	25	1980	640	1997	251

Source: FAO, Commodity Reference Series, 1998

It therefore follows that there is no economic stimulation for expanding and increasing the capacities of sugar factories. The situation may however be improved if the following are considered:

- Modernization and improvement of the efficiency of sugar production. The main objective in so doing is to decrease production costs through the improvement of both agricultural and industrial yields as well as by making better use of the inputs in sugar production.
- Increasing product diversification in sugar production through the economic use of residues and residuals.
- Establishment of fair international agreements in defence of prices and markets.

As discussed in the previous Chapters, the value-added in sugar production might be increased through the diversification of sugar production in order to attain a favourable economic balance. Production and commercialization of sugar cane by-products through the production of waxes, animal feed, alcohol, yeast *Saccharomyces* and *Torula*, particle boards, paper, furfural and renewable energy (biogas, electric power by cogeneration and alcohol), are potential means of improving the economic attractiveness of producing sugar from sugar cane.

An example of the aggregated value that can be attained with the use of fuels and energy generated during sugar cane production is shown in Table 59.

Table 59 - Aggregated value of integrating by-products into sugar production

Product	Indicator	Value	Oil Equivalent
(10 ³ \$/year)	(t/d)		
Filter cake (t/d)	175	-	-
- biogas (m ³ /d)	7 000	112.20	3.4
- fertilizer (t/d)	40.3	86.70	-
Molasses (t/d)	150	-	-
- alcohol (t/d)	33	315.00	21.0
- biogas (m ³ /d)	13 230	96.00	6.4
- fertilizer (t/d)	2.84	0.15	-
Electric energy (MWh/d)	600	5 940.00	180.0
Sugar (t/d)	500	19 800.00	-
TOTAL	-	26 350.00	210.8
Increase	-	6 550.00	-

Source: Valdes, *et al.*, (1994)

The processing of sugar by-products has the potential to:

- Increase the efficiency of the sugar factories to increase sugar yields and decrease production costs.
- Increase the utilization of the residues from the crop and industry for the production of by-products such as animal feed, particle boards, pulp and paper, alcohol, yeast, furfural, fertilizers, etc.
- Increase the skill of the operating personnel both in agriculture and industry.

Use of currently available technologies as well as those under development can improve the economic potential of sugar production. Development of by-product processing can result in employment as well as in the production of a diversity of products of commercial value. New sources of renewable energies and fuels that do not have a negative effect on the environment can also be produced.

Another possibility for increasing the value of the sugar exports is to produce a sugar that fetches premium prices while avoiding penalties caused by factors such as low polarization, safety, colour, insoluble constituents and dextran.

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